NATURAL HISTORY MUSEUM

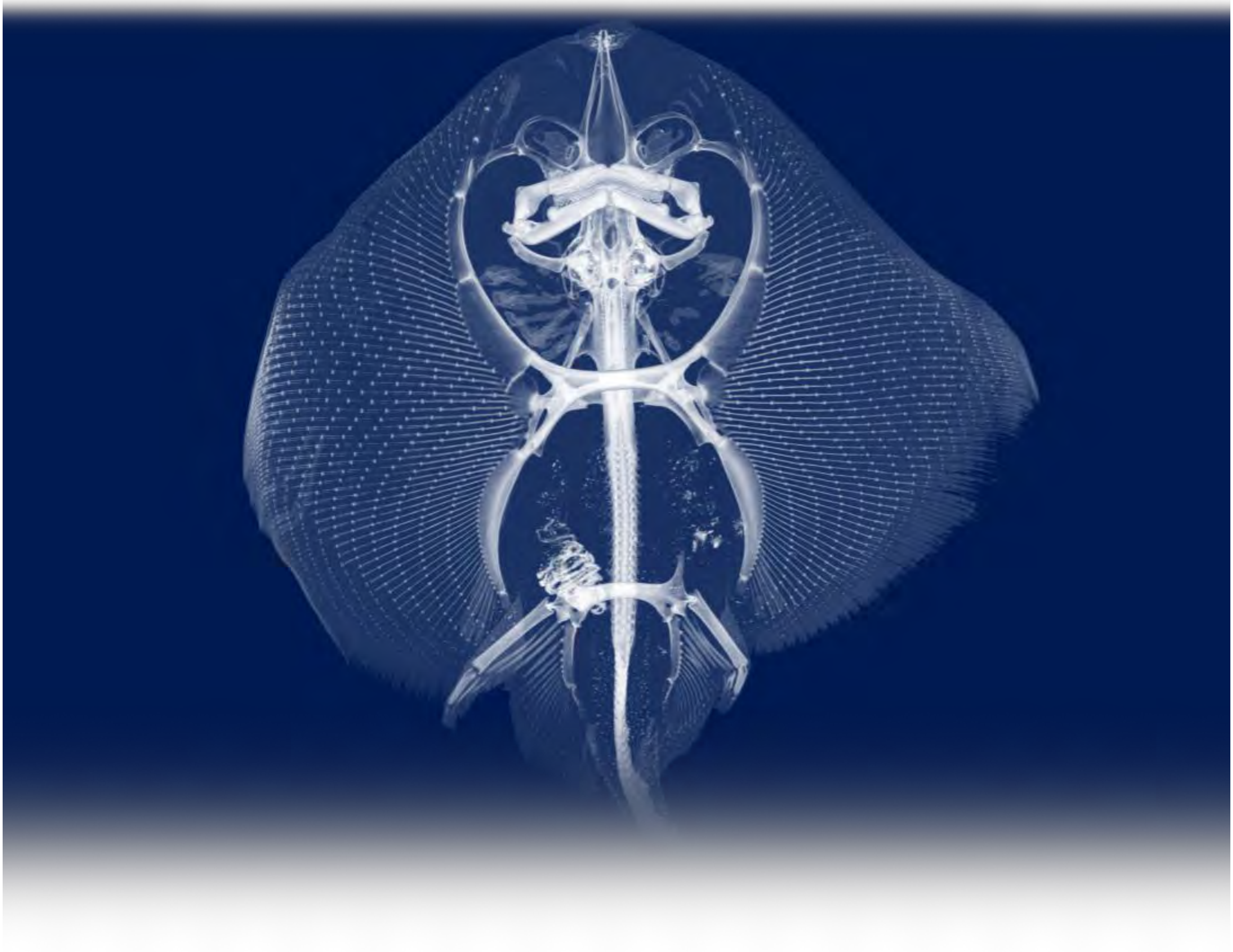
MANCHESTER 1824
The University of Manchester

# ToScA

Tomography for Scientific Advancement

3rd - 4th Sept. 2015, University of Manchester

# Programme



# Welcome to

# ToScA

Tomography for Scientific Advancement

3rd - 4th Sept. 2015, University of Manchester

In affiliation with the Royal Microscopical Society (RMS) and in partnership with CCPi Tomographic Imaging

The University of Manchester,

Oxford Road,

Manchester,

M13 9PL,

UK

**Welcome to the Tomography for Scientific Advancement symposium (ToScA) 2015!**

Following on from the success of ToScA 2014 we aim to continue to provide a platform for sharing ideas and progress, as well as innovation. Furthermore, this is the first year ToScA has incorporated Material Science as a session in the symposium and will continue to do so in the coming years. The organising committee has taken great pleasure in introducing lightning talks alongside the poster entries to ensure that the programme is as interactive as possible. This year we have 10 invited speakers, 23 contributed oral presentations and 23 posters with accompanying lightning talks. ToScA promises a community-led approach, where topics for discussion are chosen by the delegates and an opportunity to explore the direction of tomography is provided. The evening reception and symposium dinner at the Manchester Museum will provide a perfect environment for networking with academics, industry and researchers. ToScA 2015 continues with the tradition of the image and poster competitions, and promises to provide a full and diverse scientific programme. On behalf of the entire organising committee, I hope you will find the symposium interesting and stimulating and I wish you a warm welcome to Manchester.

I look forward to seeing you at the symposium,

Dr Farah Ahmed — ToScA Chair

May I extend a very warm welcome to all delegates, sponsors and speakers to The University of Manchester; proud hosts of the 3rd annual conference on Tomography for Scientific Advancement (ToScA). The University is home to the Henry Moseley X-ray Imaging Facility, a world leading suite of X-ray imaging systems, and the prestigious Manchester Museum. It is fitting that ToScA comes to Manchester in 2015, the International Year of Light, as we open our recently renovated laboratory space and mark 100 years since the death of the facility's namesake, Henry Moseley. A particular focus of this year's conference is to encourage young scientists to participate and I look forward to many stimulating talks by our future experts.

Professor Philip Withers — ToScA Co-chair

MANCHESTER 1824
The University of Manchester

EPSRC
Engineering and Physical Sciences Research Council

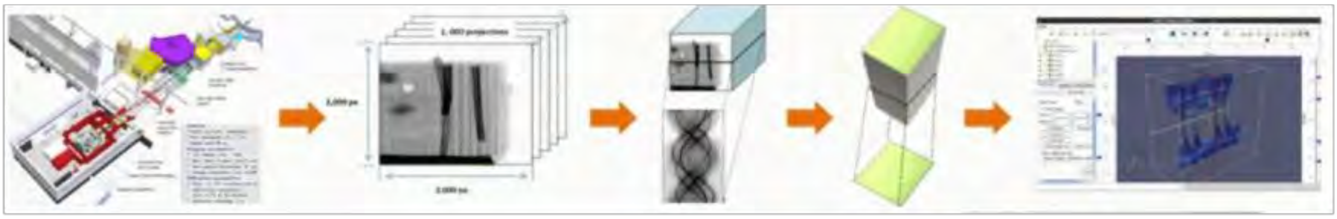
Science & Technology Facilities Council

# Collaborative Computational Project in Tomographic Imaging: www.ccpi.ac.uk

# CCPi Tomographic Imaging

CCPi aims to provide the UK tomography community with a toolbox of algorithms that increases the quality and level of information that can be extracted by computer tomography. Chaired by Prof Philip Withers (University of Manchester) and co-ordinated by staff in the Scientific Computing Department of the Science and Technology Facilities Council it is led by a working group of experimental and theoretical academics with links to the Diamond Light Source, ISIS Neutron Spallation Source and Industry

Acquire | Calibrate/Correct | Reconstruct | Quantify & Analyse



The CCPi aims to:

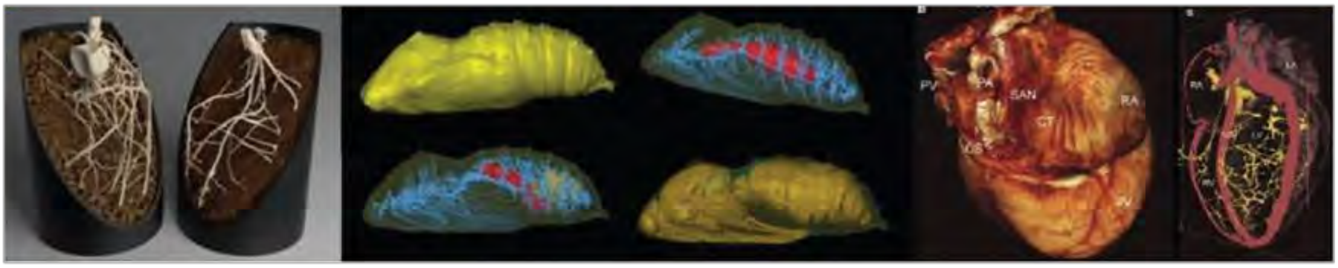
- bring together the imaging community
- maximise return on investment in software development
- ensure longevity, sustainability and re-use of code

We have special interest groups in image reconstruction, image quantification, image-based modelling and instrumentation.

Resources and Activities:

- Software Developer Workshops
- Tomography software show-and-tells
- Explore the CCPi channel on YouTube
- Data archive on CCPi zenodo.org collection
- EU COST network links

**Active joint ventures with Imaging CCP networks including the new CCP PET/MR**
**www.ccppetmr.ac.uk/**



*Images: E. Yang, S. Nagella, W. Kockelman (IMAT/STFC); D. Kazanksev, R. Atwood (DLS); S. Mairhofer (Nottingham); T. Lowe, R. Stephenson (Manchester); R. Fowler, M. Turner (STFC)*

**Want to know more? Visit www.ccpi.ac.uk** and join over 300 Tomographic Imaging practitioners by emailing: **ccpi@stfc.ac.uk**

**The CCPi is funded by the Engineering and Physical Sciences Research Council**

# Pre-Conference Activities

## Free Pre-ToScA conference: CCPi Imaging Workshops

The University of Manchester welcomes researchers at all levels to the CCPi imaging workshops where delegates will gain insights from and engage in troubleshooting sessions with specialists in Drishti/Prayog and Avizo. The two half-day sessions will be held at the Photon Science Institute, home to the Henry Mosley X-Ray Imaging Facility, on the 2nd September (immediately prior to the Tomography for Scientific Advancement Symposium on 3rd-4th September).

Confirmed speakers on Wednesday 2 September include:

- Morning from 10am; Ajay Limaye (Drishti) "New topics and advanced use within version 2.6 of Drishti including updated version of Paint (release in July 2015; https://github.com/AjayLimaye/drishti/releases)"

- Afternoon from 1:30pm; Remi Blanc and Joseph Baptista (FEI) "Fibre analysis with Avizo 3D analysis software (http://www.avizo3d.com)"

Abstract:

The presentation will highlight different usages of Avizo for tackling with fibrous materials. We consider two major use cases. First, in the case of high magnification with resolved fibres, we will present our recent XFibres extension for tracing the center line of cylindrical fibres and extracting statistics about the length, orientation, or curvature. The second use case will consider woven composites imaged at lower magnification, where individual fibres cannot be distinguished but the oriented texture of the yarns is visible. We will detail an advanced workflow for classifying the yarns based on their orientation (http://www.avizo3d.com).

Places are limited and allocated on a first come, first serve basis. To book your place, please e-mail your name, institution and any dietary requirements to kate.a.meade@manchester.ac.uk

# Day 1

## Morning

Following registration there will be an opening speech to welcome you to the symposium, which will then begin with the first session on CT – Past, Present and Future.

During the morning break, delegates are welcome to explore the trade exhibition. The exhibition will remain available throughout the rest of the symposium. There will also be an opportunity to take a 20 minute tour of the HMXIF. To find out more about these visits please ask a member of Team ToScA during registration.

After the break, the mornings events will conclude with the second session of the symposium on Understanding Materials, followed by an hour break for lunch.

## Afternoon

There will be a short break between the third and last sessions of the day. At the end of the final session, there will be a discussion panel looking at the most highly voted for topic suggestions (a poster board to vote on and suggest topics will be located in the exhibition area throughout the day).

## Evening

***Drinks Reception:***

A drinks reception will be held in the Fossils Gallery of Manchester Museum following the formal programme on the 3rd September.

***Nikon Image competition:***

The competition entries will be on display during the drinks reception. The winner and runners-up will be announced during the symposium dinner.

***CCPi Poster competition:***

The poster entries will be on display during the drinks reception. The winner and runners-up of the competition will be announced during symposium dinner.

***Symposium Dinner:***

Following the drinks reception, delegates with tickets for the dinner, are invited to enjoy a three course evening meal. The meal will be served in the main gallery of the Museum under the gaze of the Museum's very own *Tyrannosaurus rex*, Stan.

# Symposium Activities

## Day 2

### Morning

The final day of the conference will open with the Earth and Space session.

During the break there will be another chance to visit the HMXIF, before the morning talks continue with CT and Complimentary Technique, before an hour lunch break.

The ToScA group photo for all delegates, exhibitors, speakers and the ToScA organising committee will take place in this first break, so please join us in the exhibition area to be in the photo.

### Afternoon

Between the two afternoon sessions there will be a short tea break and a final chance to visit the trade exhibition. The symposium will then conclude with a second discussion panel.

©NHM

09:00 - 09:30 Morning registration

09:30 - 10:00 Introduction by Dr Farah Ahmed (chair) and Professor Philip Withers (co-chair)

## Session 1: CT – Past, Present and Future

| Time | Speaker | Title |
|---|---|---|
| **10:00-10:30** | **Dr Leah Lavery**<br>*Carl Zeiss* | **Approaching Realism – What you can do with 3D X-ray Microscopy?** |
| 10:30-10:45 | Dr Winfried Kockelmann<br>*STFC Rutherford* | IMAT: a new neutron imaging facility for the UK materials science communities |
| 10:45-11:00 | Dr Graham Davis<br>*Queen Mary University of London* | X-ray filters: what do they do? |
| 11:00-11:15 | Sophia Coban<br>*University of Manchester* | The effects of tomographic scans with fewer radiographs on the image reconstruction |

**Session keynote speakers in bold**

11:15 - 11:45 Tea break (Trade exhibition and HMXIF tours)

## Session 2: Understanding Materials

| Time | Speaker | Title |
|---|---|---|
| **11:45-12:15** | **Professor James Marrow**<br>*University of Oxford* | **Studying the fracture process zone in a heterogeneous brittle material (polygranular nuclear graphite) by synchrotron computed tomography, image correlation and X-ray diffraction** |
| 12:15-12:30 | Dr Samuel McDonald<br>*University of Manchester* | Mapping grains in 3D by laboratory X-ray diffraction contrast tomography |
| 12:30-12:45 | Dr David Eastwood<br>*University of Manchester* | Optimizing In situ synchrotron X-ray phase contrast tomography for the study of electrochemical lithium microstructure formation |
| 12:45-13:00 | Xuekun Lu<br>*University of Manchester* | Anisotropic fracture in dentin under *in-situ* nanoscale 4-D imaging |

13:00 - 14:00 Lunch (Trade exhibition)

# Schedule - Thursday 3rd

## Session 3: Data Handling and Visualisation

| Time | Speaker | Title |
|---|---|---|
| **14:00-14:22** | **Dr Mark Basham**<br>*Diamond Light Source* | **5TB a Day and Counting, Addressing the Data Deluge at Diamond Light Source** |
| **14:23-14:45** | **Dr Remi Blanc**<br>*FEI* | **3D Visualization for Data Exploration and Visual Assessment of Image Processing Results in Amira/Avizo** |
| 14:45-15:00 | Dr Nghia Vo<br>*Diamond Light source* | Feasibility of Simulated Annealing Tomography |
| 15:00-15:15 | Dr Valeriy Titarenko<br>*University of Manchester* | Approaches for ring artefact suppression in CT |

15:15 - 15:45 Tea break (Trade exhibition and group photo)

## Session 4: Museum Science and Cultural Heritage

| Time | Speaker | Title |
|---|---|---|
| **15:45-16:15** | **Professor Phillip Manning**<br>*University of Manchester* | **STEAM-powered Imaging** |
| 16:15-16:30 | Dr Andrew Nelson<br>*University of Western Ontario* | Bubbles in the Bullion – the microCT analysis of ancient coins |
| 16:30-16:45 | Dr Nesrine Akkari<br>*Natural History Museum Vienna* | A new dimension in documenting new species: High-detail imaging for myriapod taxonomy and first 3D cybertype of a new millipede species (Diplopoda, Julida, Julidae) |
| 16:45-17:00 | Nicole Ebinger-Rist<br>*Landesamt für Denkmalpflege* | Archaeology meets Computed Tomography-Examination and Uncovering of a Celtic Princess |
| 17:00-18:00 | **Lightning Talks and Panel Discussion** | |

18:00 - 19:15 Drinks Reception, Poster and Image Competition

19:15 - 22:15 Symposium Dinner and Award Ceremony

## Session 5: Earth and Space

| Time | Speaker | Title |
|---|---|---|
| **09:30-10:00** | **Dr Ryan Zeigler**<br>*NASA* | **Micro Computed Tomography as an Enhancement Tool in the Curation of Apollo Samples** |
| 10:00-10:15 | Dr Matthew Pankhurst<br>*University of Leeds* | How much, how far? Volcanic ash measurements using XMT deliver next-generation near-real-time dispersal prediction potential |
| 10:15-10:30 | Dr Victoria Egerton<br>*University of Manchester* | Synchrotron-based mapping of bioenvironmental signatures in fossils |
| 10:30-10:45 | Dr Ria Mitchell<br>*The Natural History Museum* | X-Ray micro-CT imaging of Cryptogamic Mineral Substrates: a novel approach to categorising the structure and interactions between mineralogical material and primitive terrestrial organisms |

**Session keynote speakers in bold**

10:45 - 11:15 Tea Break (Trade exhibition and HMXIF tours)

## Session 6: CT and Complementary Techniques

| Time | Speaker | Title |
|---|---|---|
| **11:15-11:45** | **Professor Stuart Stock**<br>*Northwestern University* | **X-ray diffraction tomography and 3D strain mapping** |
| 11:45-12:00 | Dr Bartlomiej Winiarski<br>*University of Manchester* | High resolution serial sectioning tomography |
| 12:00-12:15 | Ronald Seidel<br>*Max Planck Institute* | Distilling principal relationships of 3D tiling arrangements in growing mineralized elasmobranch cartilage. |
| 12:15-12:30 | Professor Philip Withers<br>*University of Manchester* | Spectroscopic X-ray tomography for 3D chemical imaging |

12:30 - 13:30 Lunch (Trade exhibition)

# Schedule - Friday 4th

## Session 7: Bioengineering and Life Sciences

| Time | Speaker | Title |
|---|---|---|
| **13:30-14:00** | **Dr Bert van Rietbergen**<br>*Eindhoven, University of Technology* | **Analysis of bone structure and strength using micro-Computed Tomography and Finite Element techniques** |
| 14:00-14:15 | Jennifer Anné<br>*University of Manchester* | X-raying bones in the 21st century |
| 14:15-14:30 | Dr Gavin Taylor<br>*Lund University* | Using microCT to see through an insect's eyes |
| 14:30-14:45 | Dr Robert Stephenson<br>*Liverpool John Moores University* | Contrast enhanced Micro-CT of the heart; applications in functional micro-anatomy and electrical modelling |
| 14:45-15:00 | Dr Ciaran Hutchinson<br>*Great Ormond Street Hospital* | Medical applications of Micro-Computed Tomography New Diagnostic Possibilities |

15:00 - 15:30 Tea break (Trade exhibition)

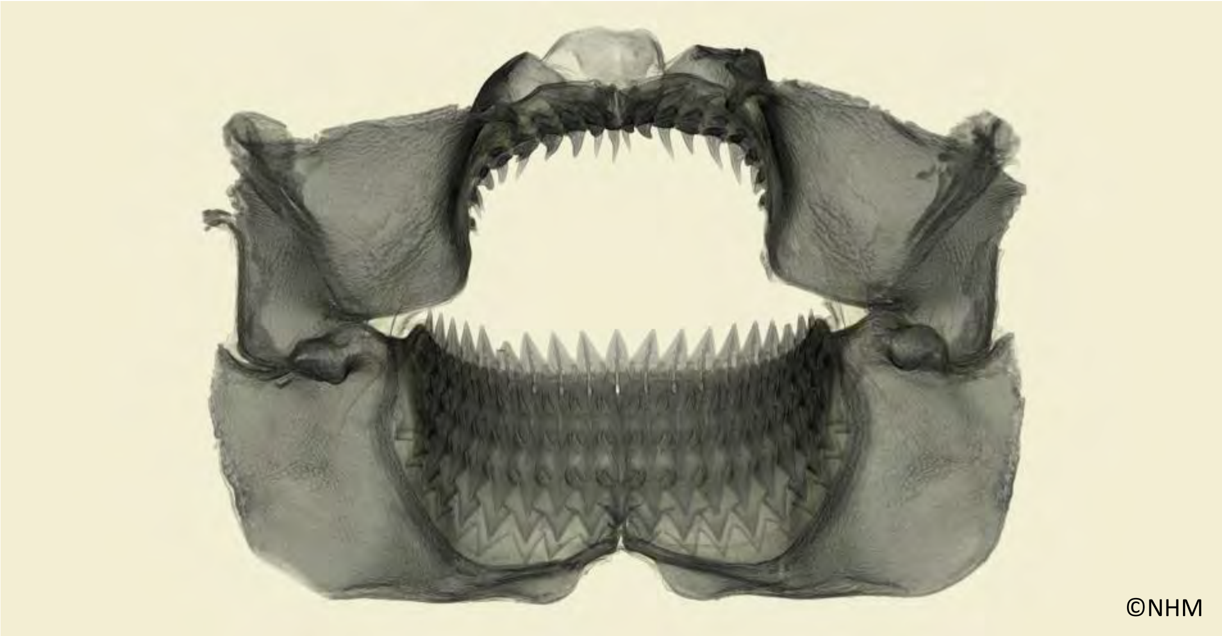
## Session 8: Data Quantification

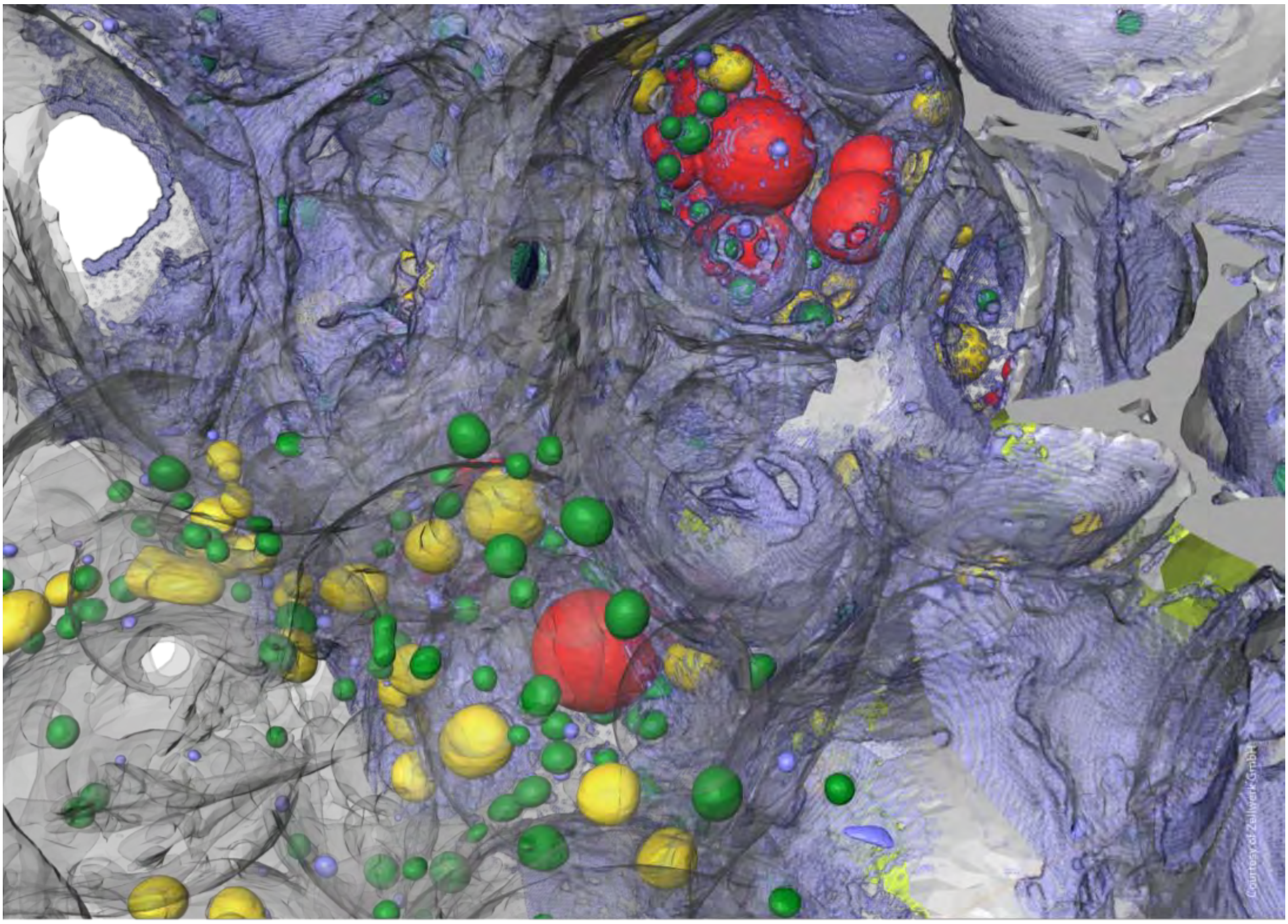
| Time | Speaker | Title |
|---|---|---|
| **15:30-16:00** | **Professor Adrian Sheppard**<br>*Australian National University* | **Extending the value of X-ray micro-CT for quantitative analysis** |
| **16:00-16:15** | **Andrew Ramsey**<br>*Nikon Metrology* | **Moving CT out of the Research Department and onto the Production Line** |
| 16:15-16:30 | Dr Kate Dobson<br>*Ludwig-Maximilians-Universität München* | Quantifying dynamic rheology, phase interactions and strain localisation in magmas using high-speed x-ray tomography |
| 16:30-16:45 | Peter Swart<br>*Imperial College* | Characterising the neck motor system of the blowfly |
| 16:45-17:45 | **Panel Discussion** | |

18:00 End of Symposium

# Session Chairs

| | |
|---|---|
| **CT - Past, Present and Future** | **Professor Philip Withers**<br>University of Manchester |
| **Understanding Materials** | **Professor Stuart Stock**<br>Northwestern University |
| **Data Handling and Visualisation** | **Dr Ajay Limaye**<br>Australian National University |
| **Museum Science and Cultural Heritage** | **Dr Farah Ahmed**<br>The Natural History Museum |
| **Earth and Space** | **Professor Margaret Collinson**<br>Royal Holloway University of London |
| **CT and Complementary Techniques** | **Dr Martin Turner**<br>CCPi |
| **Bioengineering and Life Sciences** | **Dr Graham Davis**<br>Queen Mary University of London |
| **Data Quantification** | **Dr Ken Johnson**<br>The Natural History Museum |





## Dr Leah Lavery

Leah Lucas Lavery is a materials scientist for Carl Zeiss X-ray Microscopy. She holds a B.S. in Materials Science & Eng. from Northwestern University, and received her Ph.D. in Materials Science from Arizona State University (ASU). She has research experience at number institutions such as PARC, US Army-ASU Flexible Display Centre, National Institute of Standards and Technology (NIST) and Bell Labs. Dr. Lavery has published numerous papers on the topics of advanced materials characterization, organic semiconductors, and flexible and printed electronics.

## Professor James Marrow

Professor James Marrow is the James Martin Chair in Energy Materials, and co-directs the Nuclear Programme in the Oxford Martin School.  He joined the Oxford University Department of Materials in September 2010, from Manchester where he directed the Materials Performance Centre. He obtained his undergraduate degree and PhD in Materials Science at Cambridge University, and became a lecturer at Manchester following postdoctoral research at Oxford and Birmingham Universities. Professor Marrow's research focuses on degradation of structural materials and the role of microstructure, investigating fundamental mechanisms of damage accumulation using novel materials characterisation techniques. He has pioneered imaging methods for quantification and observation of cracks in engineering materials, and is now leading in the area of three-dimensional studies of damage, using high-resolution X-ray computed tomography and measurement of the three-dimensional full field displacements by digital volume correlation. Professor Marrow has established a close interaction with the Diamond Light Source synchrotron facility at the Rutherford Appleton Laboratory. This work has pioneered the three-dimensional characterisation of damage processes in energy and nuclear materials, supporting the validation of simulation tools to forward predict materials performance.

## Dr Remi Blanc

Remi Blanc received his MSc and PhD degrees from the University of Bordeaux, France, in 2003 and 2007 respectively, studying image analysis and investigating spatial statistics for composite materials characterization. He worked as a postdoctoral fellow at ETH Zürich from 2008 to 2011 in medical image analysis and statistical shape modelling. His research interests relates to statistical methods for image analysis, estimation and confidence assessment. Since 2013, he has been Product Marketing Engineer at FEI, where he provides expertise on the 3D image visualization and analysis software solutions Amira and Avizo.

# Keynote Speaker Biographies

## Dr Mark Basham

Dr Mark Basham is a Senior Software Scientist at Diamond Light Source, the UK's national synchrotron facility located on the RAL campus in South Oxfordshire. Mark was awarded his Physics PhD in surface science simulation from Reading University, he then moved to data analysis of synchrotron data after working with experimental colleagues in the field. Mark is a strong believer in Open Source software, spending a lot of his time working on open data analysis software projects such as Dawn Science (www.dawnsci.org) and Savu (https://github.com/Diamond Light Source/Savu), the latter of which is a pipeline for reconstructing and processing the large and diverse tomographic datasets collected at synchrotrons. Mark has a real passion for public engagement, he is the creator of the Lego Beam line (#legobeamline) which helps to explain how Synchrotron experiments are performed, he also works with the communications team at Diamond, recently establishing several Drishti Prayog touch screen systems. Currently Mark works closely with his colleagues around the Rutherford Appleton Laboratory campus and university collaborators on enhancing the Savu project to be able to process as many of the exciting new methods for tomographic imaging which are emerging. Mark can be contacted by email at mark.basham@diamond.ac.uk or @basham_mark on twitter.

## Professor Phillip Manning

Professor Phil Manning is Director of the International Centre for Ancient Life (ICAL) in the School of Earth, Atmospheric and Environmental Sciences (SEAES) at the University of Manchester. In addition, he is a Fellow of the Explorer's Club (New York, USA) and a Research Associate at the American Museum of Natural History (New York, USA). Driven by a passion to study the evolution of life on earth, he has built a multi-disciplinary and international research portfolio that has received worldwide attention. His main research areas include synchrotron-based imaging and spectroscopy, vertebrate ichnology, vertebrate biomechanics, locomotion and finite element modelling, palaeopathology, arthropod palaeoecology, structural biomaterials, biomolecules in the fossil record, dinosaur taphonomy and soft-tissue preservation. He has numerous collaborators both nationally and internationally with his current research at Manchester primarily focused on integrating research disciplines to solve key questions in the palaeobiology and locomotion of extinct vertebrates. He is an enthusiastic and passionate advocate of communicating and engaging the public, with his most notable outreach activities include leading the Dino Zone exhibition at the Cheltenham Science Festival (2015) and annual displays at the Royal Society Summer Exhibition (2012 and 2014).

## Dr. Ryan Zeigler

Dr. Ryan Zeigler is the Apollo Sample Curator in the Astromaterials Curation and Acquisition Office at NASA's Johnson Space Centre in Houston Texas. He oversees the protection, preservation, and distribution of the 842 pounds of lunar samples collected by the Apollo astronauts. The Apollo samples are stored and processed in a clean room facility at the Johnson Space Centre, part of a larger complex of clean rooms that house all eight of NASA's astromaterials collections. Originally specializing in electron-beam and neutron-activation based studies of lunar samples, Dr. Zeigler has recently been utilizing micro-CT as part of the core curation process for Apollo samples. Johnson Space Centre will be bringing a state-of-the-art micro-CT scanner online for dedicated use with astromaterials within the next 12-18 months.

## Professor Stuart R. Stock

Dr. Stock's background is in materials science, and his work since 2000 has cantered on mineralized tissue characterization using synchrotron and laboratory sources of x-radiation. He is based at the Feinberg School of Medicine, Northwestern University. Dr. Stock employs x-ray diffraction for some of these studies and has written the text 'Elements of X-ray Diffraction', 3rdEd. (B.D. Cullity and S.R. Stock). He has actively employed microComputed Tomography since his first paper using it appeared in 1986, has written the monograph 'MicroComputed Tomography: Methodology and Applications', and edited the four most recent volumes in the 'Developments in X-ray Tomography' series.

## Andrew Ramsey

Andrew Ramsey graduated from the University of Cambridge in 1986 and joined the UK Atomic Energy Authority's Harwell Laboratory near Oxford to develop software for non-destructive testing (NDT) image analysis. He has worked in X-ray Computed Tomography (CT) since 1992 and helped develop one of the world's first PC-based CT systems. While at Harwell he worked closely with X-Tek Systems and finally joined them in 1999 as a software engineer. There he developed X-Tek's first CT reconstruction software as well as helping Sales with technical enquiries. Andrew moved into the Sales Department in 2006 giving the sales staff and agents worldwide technical support as well as promoting CT technology. Following the acquisition of X-Tek by Metris and subsequently by Nikon, Andrew is now part of Nikon Metrology's X-ray Centre of Excellence supporting CT systems, agents, sales staff and customers worldwide.

# Keynote Speaker Biographies

## Dr. Bert van Rietbergen

Dr. Bert van Rietbergen is an associate professor in the Orthopaedic Biomechanics Section of the department of Biomedical Engineering at the Eindhoven University of Technology. He received his M.S. in mechanical engineering from the Eindhoven University of Technology in 1988. After graduation, he was appointed at the Orthopaedic Research Lab of the University of Nijmegen, The Netherlands, where he received his PhD (cum laude) in 1996. In 1997 he moved to Switzerland for a postdoc position at the Institute of Biomedical Engineering of the ETH in Zürich. In 1999 he moved back to the Eindhoven University of Technology to be appointed at the newly formed department of Biomedical Engineering. Most of his research is aimed at the evaluation of bone structural and mechanical properties for the study of bone diseases (osteoporosis) and implant failure. During his PhD period he has developed a new computational approach for mechanical analysis of bone structures from high-resolution images. Over the last decade his work has focused on clinical applications of this approach. As of June 2015, Bert van Rietbergen has published some 103 papers in peer-reviewed journals with a total citation record of 5939 and has a Hirsch-index of 44. On an ad-hoc basis he acts as a consultant for pharmaceutical and orthopaedic industries and on a regular basis for Scanco medical AG.

## Professor Adrian Sheppard

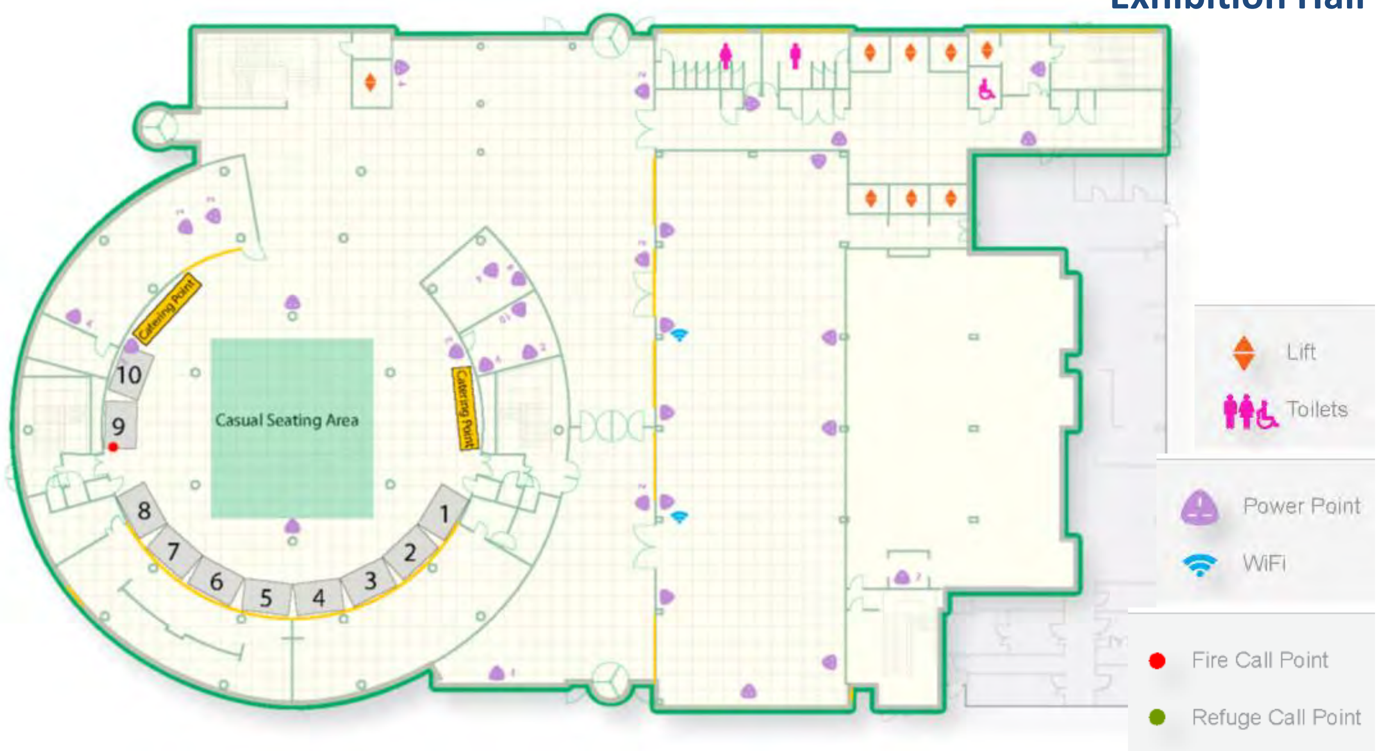
Associate Professor Adrian Sheppard completed his B.Sc (hons) degree in Mathematical Physics at The University of Adelaide in 1992 and his PhD degree in Physics at the Australian National University (ANU) in 1996 in the area of nonlinear optics. He has held research positions at the Université Libre de Bruxelles, the University of New South Wales and the Australian National University, where he has worked since 2000. He is the originator and project leader for the Mango software toolkit for scalable imaging processing and is one of the founders of the ANU's X-ray micro-CT facility, which seeded the successful spin-off company Digital Core, now part of FEI. He is currently head of the Department of Applied Mathematics in the Research School of Physics and Engineering at ANU. His research interests include tomographic imaging, parallel algorithms for image processing, the characterisation of shape and multi-phase fluid flow in porous media.

University Place

# ToScA and Trade exhibition map

## 3rd Floor
## Lecture Theatre


## Ground Floor
## Exhibition Hall



# Symposium exhibitors

RMS

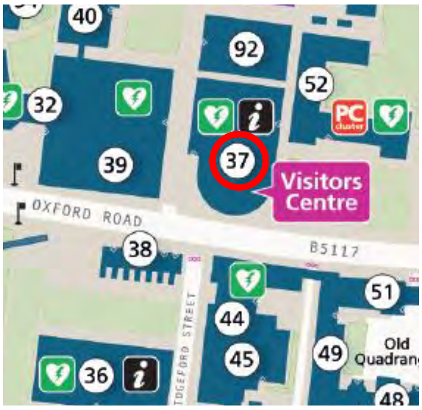
| | |
|---|---|
| Table 1 | bluescientific |
| Table 2 | CCPi Tomographic Imaging |
| Table 3 | DEBEN |
| Table 4 | FEI™ |
| Table 5 | LaVision FOCUS ON IMAGING |
| Table 6 | Nikon |
| Table 7 | NORTH STAR IMAGING NSI AN ITW COMPANY |
| Table 8 | VOLUME GRAPHICS SOLUTIONS ABOUT VOXELS |
| Table 9 | ZEISS |

LaVision FOCUS ON IMAGING
NORTH STAR IMAGING NSI AN ITW COMPANY
DEBEN
bluescientific
VOLUME GRAPHICS SOLUTIONS ABOUT VOXELS

# How to Find Us


The University of Manchester is a short walk away from Manchester Piccadilly train station (see map to the right). Exit the station onto London road, turn right onto Grosvenor St and then turn left onto Oxford Road. The conference is being held in the University Place within the campus (number 44) on oxford road opposite the visitors centre.

The 147 bus goes from Fairfield Street/Piccadilly Rail Station (Stop D) and stops at Oxford Road/Aquatics Centre near the university campus.

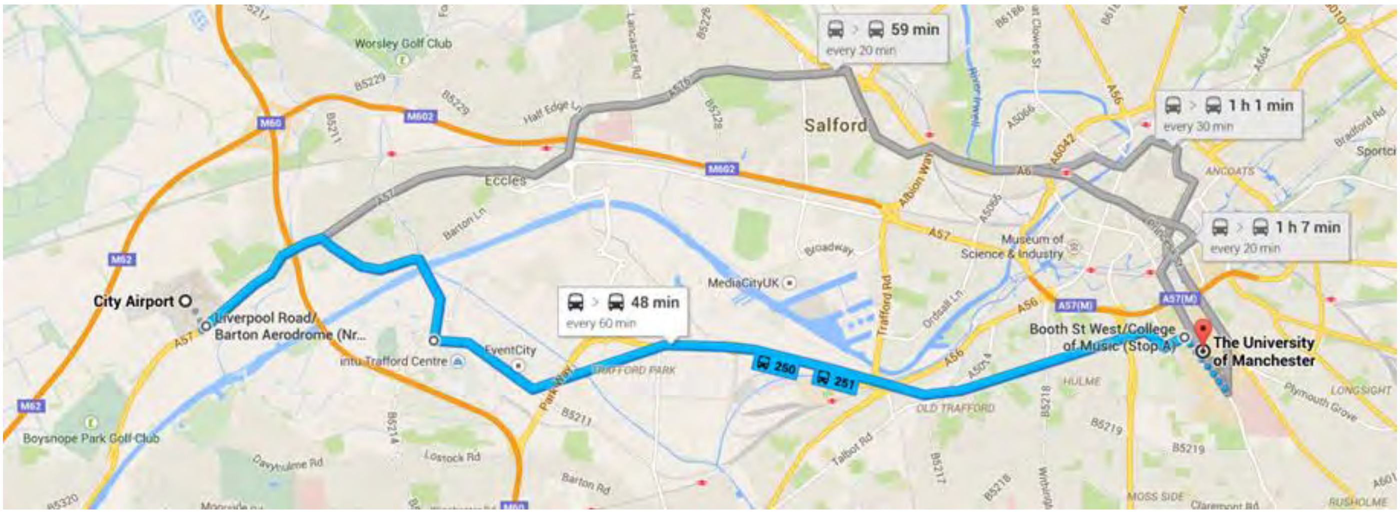



Parking for delegates is also available at either car park B (Aquatics Car Park), on Booth Street East or at D on Booth Street West. For information on pricing visit http://www.estates.manchester.ac.uk/services/operationalservices/carparking/carparks/

The Campus can also be reached from the airport via bus (route shown below). Take the number 100 bus from Liverpool Road/Barton Aerodrome to Trafford Centre Bus Station then the number 250 to Booth St West/College of Music (Stop A) then walk down Oxford road to the university campus.

Taxis are also available from both the airport and the train station to the campus, these are some local companies:

Street Cars Manchester: 0161 228 7878 Radio Cars Manchester: 0161 236 8033 Euro Cars (Manchester): 0161 232 1111



To Ardwick and the Manchester Apollo
Dryden Street Nursery
UPPER BROOK STREET A34
COTTENHAM STREET
WATKIN CLOSE
YORK STREET
Aquatics Centre
BOOTH STREET EAST
BOOTH STREET WEST
ROSAMOND STREET WEST
Royal Northern College of Music
B5117
OXFORD ROAD
University Place
Visitors Centre
Manchester Museum
BRIDGEFORD STREET
COUPLAND STREET
Old Quadrangle
Rear Quadrangle
BRUNSWICK STREET
DOVER STREET
BURLINGTON STREET
LIME GROVE
PORTSMOUTH STREET
RUMFORD STREET
ACKERS STREET
GRAFTON STREET
NELSON STREET
Wellcome Trust Clinical Research Facility
A&E
Nowgen Centre
Student Services and Accommodation Office
Contact Theatre
Whitworth Park
DILWORTH STREET
CECIL STREET
LLOYD STREET
HIGHER CAMBRIDGE STREET
CAMBRIDGE STREET
Sat Nav
Oxford Rd
M13 9PL
McDougall Centre and Manchester Science Park (see inset map)

NATURAL HISTORY MUSEUM

# Places to stay

MANCHESTER 1824
The University of Manchester

**Holiday Inn Express Manchester Cc Oxford Road:**

The Holiday Inn is located at the top oxford Road 8 minutes' walk from the university. Rooms are allocated on arrival and include en suite facilities and internet access.

Booking available at: www.ihg.com/holidayinnexpress

**Macdonald Manchester Hotel & Spa:**

The rooms at Macdonald Manchester Hotel & Spa include some of the largest in the city. The rooms come with complimentary Wi-Fi, docking station, flat screen TV with Freeview, air conditioning.  The Hotel is located on London road and is a 15 minute walk from the University.

Booking available at: www.macdonaldhotels.co.uk

**Hotel ibis Manchester Centre Princess Street:**

The Hotel ibis can be found on Charles Street and is only a 10 minutes away from the university campus. Lunch and dinner are available, with Wi-Fi included as well as en suite services.

Booking available at:  www.ibis.com


**Pendulum Hotel Manchester Conference Centre:**
The Pendulum Hotel within 10 minutes walking distance of the university campus. Rooms include en suite and internet facilities.
10 discounted rooms are available up to 6 weeks prior to the arrival date.
These rooms can be booked using the reference: GA00422
Booking available at:  http://www.pendulumhotel.co.uk/hotels-in-manchester
Tel: +44 (0)161 955 8000

**DoubleTree by Hilton Manchester Piccadilly:**

The DoubleTree is situated in Piccadilly place, adjacent to Manchester Piccadilly station. Facilities include Apple iMacs, complimentary WiFi access, and a variety of satellite and digital TV channels. The hotel is within 20 minutes walking distance to the university.

15 rooms have been reserved and can be booked using the code TOSCA via manchesterpiccadilly.doubletree.com (insert the allocation code in the "group code" field) or by contacting the in-house reservations team on 0161 242 1991 and quoting the code.

ZEISS FEI™ CCPi Tomographic Imaging Nikon

# ToScA Committee 2015

**Chair:** **Dr Farah Ahmed**

**Co-chair:** **Professor Philip Withers**

### Local Committee (University of Manchester):

Dr Kate Meade

Dr Martin Turner

Dr Russell Garwood

Dr Sarah-jane Clelland

Paulina Hoyos

Professor Phillip Manning

### Planning Committee (Natural History Museum, London):

Miriam Aczel

Callum Hatch

Dan Sykes

### Volunteers:

Dr Ali Chirazi

Edward Thomas

Dr James Carr

Noriko Griffiths

Dr Robert Bradley

Dr Tristan Lowe

Xuekun Lu

Xun Zhang

# The Museum of Manchester

Holding more than 4 million specimens and objects ranging from a reproduction cast of a fossilised *Tyrannosaurus rex* to artefacts from prehistoric Egypt. The collections housed in the Museum are used to encourage discussion on the past, present and future of the world and its inhabitants.

The first collections were introduced by the Manchester Society of Natural History in 1821 with later collections added by the Geological Society in the 1850s. The Museum opened to the public in 1888, and since then the collections have grown to include archaeological and Egyptian collections acquired through excavations supported by Jesse Haworth as well as ethnographic collections.

In addition, the Museum holds the fourth largest mollusc collection in Britain with 166,000 specimens. The Vivarium gallery contains a large collection of reptiles including some of the rarest species on the planet.

# Highlights from ToScA 2014

RMS

## Competition Winners from ToScA 2014

NORTH STAR IMAGING NSI AN ITW COMPANY

DEBEN

LaVision FOCUS ON IMAGING

bluescientific

VOLUME GRAPHICS SOLUTIONS ABOUT VOXELS

## At Manchester Museum

### Making Monuments on Rapa Nui

(Free entry, runs until 6th September)

Professor Colin Richards, an archaeologist at the University of Manchester, has worked on this new exhibition, taking a fresh look at these mysterious statues. The stone statues of Rapa Nui (also known as Easter Island) are widely recognised and fascinating archaeological objects. Explore how the statues and their top-knots were made and the role they played in day to day life. Discover where they quarried and how they were transported, as well as what they mean. This exhibition also uncovers some of the myths about the island, and the most recent theories about the end this extraordinary culture.

### Ancient Worlds

(Free entry)


The Ancient world galleries opened in 2012 marking the centenary of the first Egypt gallery to open at the Museum. The three new galleries highlight collections from ancient civilizations such around the world as well as Manchester and the region. The Galleries showcase the best of the outstanding collections from the ancient world and the stories they tell of the people who used them and discovered them.

### The Vivarium

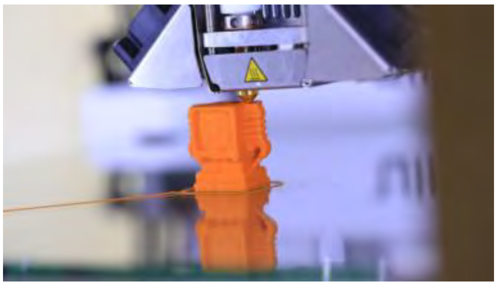
(Free entry)

The Vivarium specializes in the conservation of reptiles and amphibians. It houses a wide variety of lizards, reptiles and frogs from South America, Australia and Madagascar. The Vivarium also contains a collection of live reptiles helping to conserve some of the rarest animals on the planet and allowing the public to experience them first hand.

# What's on?

## In Manchester

**Museum of Science and Industry:**



3D: Printing the Future *(runs until 20 September 2015, free entry)*

Come Closer Wellcome Image Awards 2015 *(runs until 1 March 2016, free entry)*

The Innovation Race: Manchester's Makers Join the First World War *(runs until 1 March 2016, free entry)*

**IWM North:**

WithDraw *(runs until 6 September, free entry)*

**People's History Museum:**

Main Gallery One Democracy *(runs until 3 January 2016, free entry)*

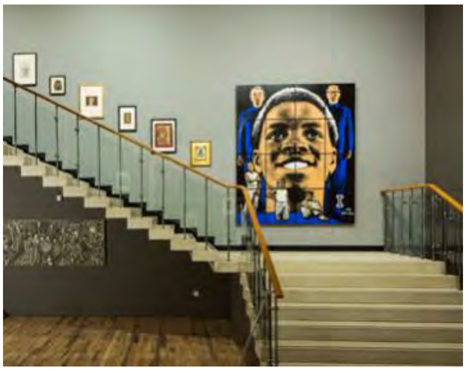
**The Lowry:**

Lowry Favourites *(Free entry)*

**The Whitworth Art Gallery:**

Portraits *(runs until 2nd November 2015, free entry)*

The 1960s *(runs until 10 January 2016, free entry)*



### Manchester Art Gallery:

House Proud *(runs until April 2016, Free entry)*

***For other events and exhibits see Timeout***

## Session 1: CT – Past, Present and Future

# Approaching Realism – What you can do with 3D X-ray Microscopy?

**Leah L. Lavery,** Masako Terada, Dave McMahon, Eric Whitehead and Brian L. Fisher

**Carl Zeiss**

Realism is a function of scale, resolution, material properties, and imaging capability. To approach realism namely providing adequate visualization or representation for any material whether it be ant anatomy or 3D printed steel, requires having the imaging capability at the appropriate scale and spatial resolution. A new field of 3D X-ray microscopy (XRM) has emerged bringing dramatic resolution and contrast improvements to X-ray tomographic imaging. Analogous to computed tomography (CT) a specimen can be imaged without physical sectioning and a complete 3D view of the object is generated. Yet X-ray microscopes provide superior spatial resolution down to the nanoscale and tunable phase contrast to image materials such as nanoscale pores in filtration membranes or entire model organisms such as zebrafish *ex vivo* up to tens of centimetres in size. This is possible because laboratory-based X-ray sources have been coupled with high resolution optically coupled detectors and in some cases X-ray focusing optics to acquire tomographic datasets with resolution down to 50 nm across a great span of sample dimensions. This signifies an improvement of at least one order of magnitude in spatial resolution relative to the limits of 'optic-free' laboratory computed tomography (CT) techniques.

Figure 1. Abdomen of a male ant (*Adetomyrma bressleri*) with extended genitalia captured by Xradia 520 Versa. Image by GraeaeX. Sample courtesy of California Academy of Sciences.

This talk will explore both the implementation of optics in nanoscale and sub-micron laboratory XRM architectures. Laboratory XRM, which emerged in the past decade from the foundations of synchrotron-based X-ray imaging optics, produces direct 3D tomographic information from opaque specimens with spatial resolutions well into the sub-micron range, even achieving 10's of nm spatial resolution for certain architectures and applications such as pharmaceuticals and fuel cells. Currently, demand is growing for applications that require 3D imaging with high resolution and high contrast and even diffraction contrast for metallurgy studies.

This talk will highlight the imaging capability of a 3D XRM with application highlights from materials and life sciences. In the first example, tomographic data was collected by Xradia 520 Versa of an ant specimen (*Adetomyrma bressleri*) for morphological studies to resolve species phylogeny. In this case to 'approach realism' required intuitive and advanced visualization. Secondly, for materials research, datasets collected at nanoscale resolution by Xradia 810 Ultra provided realistic microstructure input to improve computational transport models for polymer electrolyte fuel cells. Coupled with advanced visualization methods, three-dimensional X-ray microscopy (XRM) is a powerful sub-surface imaging technique that reveals tomography of microstructure from a range of materials, non-destructively.

# IMAT: a new neutron imaging facility for the UK materials science communities

**Winfried Kockelmann,** Genoveva Burca, Tino Minniti, Joe Kelleher, Saurabh Kabra, Shu-Yan Zhang and Federico Montesino-Pouzols

**STFC Rutherford**

Neutron imaging can provide two- or three-dimensional, spatially resolved images of the internal structures of bulk samples that are not accessible by other techniques, making it a unique tool with many potential applications. The white-beam conventional attenuation contrast methods are now well established as invaluable non-destructive inspection and quantitative measurement tools. Neutron imaging is similar to x-ray radiography and tomography in that the method produces 2D or 3D attenuation maps. However, the images often produce complementary information due to the differences between x-ray and neutron interaction mechanisms with matter. For some applications it can be useful to carry out neutron radiography or tomography at one specific neutron energy, for an energy band or for a multitude of separate energies (rather than using a white-beam with no energy discrimination) since the attenuation behaviour of materials varies with neutron energy. Energy-dependent imaging allows different materials or even different phases of the same material to be distinguished, and can also reveal microstructure properties. At a pulsed neutron source such as ISIS the energies of neutrons are straightforwardly measured via the time-of-flight technique.

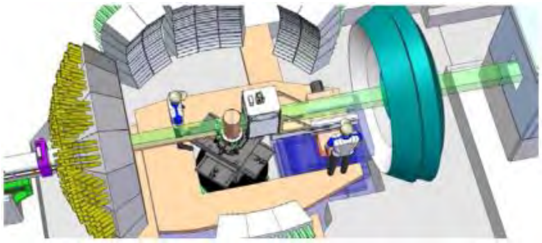


Figure 1. Outline of the IMAT instrument at the ISIS neutron source

A new neutron imaging and diffraction facility, called IMAT (Fig. 1), is currently under construction at the ISIS pulsed neutron spallation source and will take advantage of these energy-selective imaging techniques. The installation of IMAT is nearing completion with first neutrons expected in September 2015. From 2015 the instrument will enable white-beam neutron radiography and tomography as well as energy-dependent neutron imaging. IMAT will offer a spatial resolution down to 50 microns and a field of view of 200 mm. IMAT will exploit energy dependences of total cross sections of materials for contrast variation and, specifically, for mapping residual strains and texture in metals and alloys. The installation of large detector arrays for diffraction applications will be addressed in the next phase of the project. With those detectors IMAT will enable spatially resolved diffraction scans for residual strain and texture determination. IMAT will eventually allow a broad range of imaging and diffraction applications, covering a range of scientific and technological areas such as:

- Aerospace, Civil engineering & transportation: e.g. structural integrity; lifetime and failure analysis; novel welding technology, fatigue properties; novel joining methods; composite reinforcements; water repellent agents/ rising of liquids in concrete; void and density distributions in concrete;
- Power generation: e.g. novel alloys; structural integrity of steam pipework / pressure vessels / hydrogen embrittlement in Zr welds, residual stresses of casts/ weldings and weld repairs;
- Fuel and fluid cell technology: e.g. functioning and in-situ testing of gas pressure flow / fluid cells; water/lithium distributions in fuel cells/batteries; blockages, sediments;
- Earth sciences: e.g. deformation mechanisms in poly-mineralic rocks; water flow in porous media, mantle rheology, rock mechanics, spatial distribution of minerals;
- Archaeology & heritage science: e.g. inorganic materials characterisation; non-destructive characterisation and multi-component analysis of archaeological objects and objects of art; ancient fabrication techniques;
- Biomaterials and soft matter, e.g. agriculture: water uptake in plants and soil; water and hydrogen distributions in polymers and porous media.

IMAT will complement the materials analysis capabilities of ENGIN-X at ISIS, with IMAT being suited for in-situ high-intensity applications requiring medium spectral resolution, and the latter being the high-resolution strain scanning instrument. An important feature of IMAT will be 'tomography-driven' diffraction and instrument control which will permit user-friendly operation of the instrument to study structurally and geometrically complex samples.

# X-ray filters: what do they do?


## Graham Davis

### Queen Mary University of London


All laboratory X-ray microtomography (XMT or micro-CT) systems will contain some kind of physical X-ray filter to modify the X -ray spectrum. The filter is generally placed between the source and the detector and is most likely interchangeable to allow for filters of different materials and thicknesses to be used. The questions that need to be answered, in order of increasing difficulty, are: What does filtering do? Why is it necessary? How is the optimal filter selected? In order to provide a rationale for filter selection, the effect of filtering on signal-to-noise and beam hardening was modelled.

Modelling demonstrated that for a typical laboratory X-ray source, the optimal specimen transmission is around 13%, the same as for monochromatic X-rays. Because of beam hardening, the effect on transmitted flux (passing through the centre of the specimen) is far less than its effect on incident flux. Thus the observed reduction in incident intensity is not representative of the effect on signal-to-noise ratio. Beam hardening was quantified by comparing the derivative of attenuation to the projected mass of material per unit area, initially with nothing in the beam and then with enough of the same material to reduce transmission to 13%. A beam hardening factor (BHF) was defined as the ratio of these two values. This factor is reduced considerably by filtering.

Most, if not all XMT systems employ some form of beam hardening correction, but this tends to work ideally only when there is one “species” in the beam. For biological hard tissue specimens, the organic (in which we include embedding material) and inorganic phases have very different X-ray attenuation characteristics. This can lead to significant errors in measurements of mineral density even with beam hardening correction applied. Thus an “uncorrectable beam hardening factor” (UBHF) for the case where two species are present was defined. Poly methyl methacrylate (PMMA) was used for one phase (to represent both embedding material and soft tissue) and calcium hydroxyapatite (HAP) for the other (note that this model is entirely analytical and based on published X-ray attenuation data). The UBHF depends not only on what the species are, but also on which is the target species, i.e., which is the subject of measurement in the investigation. With HAP as the target, the UBHF was defined as the derivative of attenuation with projected mass of HAP per unit area with an amount of PMMA in the beam to give 13% transmission divided by the same derivative (HAP) with enough HAP in the beam to give13% transmission. This is an extreme case and would not be encountered in biological specimens, but is a useful indication of the way that filtering and voltage selection affect beam hardening errors. Here, the UBHF did fall with filtering, but not as steeply as the BHF. Variation with voltage and filtering material were also noted.

The use of these modelling tools allows a rational choice to be made for the filtering to be used in particular investigations and to set guidelines for standard filter protocols.

# The effects of tomographic scans with fewer radiographs on the image reconstruction

**Sophia B. Coban**, Philip J. Withers, and William R.B. Lionheart

**University of Manchester**

Reconstructing a 2D slice or a 3D volume from a set of insufficient tomographic data is a difficult problem, and it is often tackled with analytical reconstruction algorithms. However, these types of methods fall short on delivering a quality image due to the severe artefacts introduced by the insufficiency of the data. The presented work shows the effects of taking tomographic scans with fewer radiographs on the quality of the reconstructed images. The aim here is to show the advantages of using iterative reconstruction methods over analytical methods, which are demonstrated by a quantitative comparison. In many tomography experiments, collecting insufficient tomographic data is unavoidable; in others, it is the goal of the experiment. Depending on the application, the objective of the tomography experiment can be scanning of a patient at a lower dose to reduce the radiation exposure; or taking fast radiographs at large angle intervals to capture rapid changes in a sample. There could also be limitations that restrict the number of angles of illumination, which could be due to the hardware, the sample, or the conditions of the experiment. Another reason for taking a portion of radiographs rather than a full scan is the increasing demand in the computational memory, which becomes a challenge to store as more data is acquired.

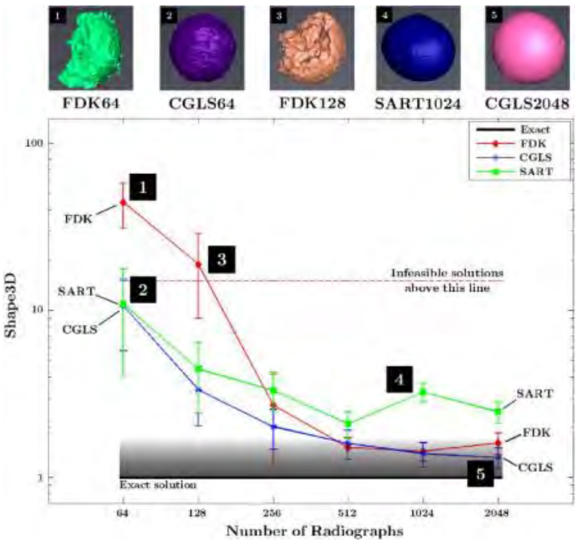



Figure 1: Results of the SHAPE3D analysis plotted with error bars in MATLAB. The black line denotes the 'perfect solution', while the shaded section denotes the acceptable results due to the standard deviation in the size of the glass beads.

Working with insufficient data introduces new artefacts that deteriorate the quality of the reconstructed images obtained with analytical methods. In this paper, we show the effects of insufficient data on the image reconstruction, and the advantages of using iterative methods in these cases. We compare the quality of the reconstructed results obtained with the popular analytical method FDK, and the iterative methods SART and CGLS; using an experimental glass bead pack dataset1 where the measurements of the sample and the beads are known. This dataset is based on the framework introduced in: acquiring 1 frame for each of 2048 radiographs; 2 frames at 1024, 4 frames at 512, 8 frames at 256, 16 frames at 128 and 32 frames for 64 radiographs. This enables a wide range of algorithm comparisons and information content optimizations to be examined. The Sophia Beads dataset are taken using the Nikon Metris Custom Bay, situated in the Manchester X-ray Imaging Facility at the University of Manchester. The FDK results were obtained using the in-house reconstruction software available with the scanner. The methods SART and CGLS were implemented in MATLAB R2014b, with the forward and back projec-tor codes written in C2. The segmentation and quantification of the results were carried out using the image-measuring techniques available in Avizo Fire 8. The quantification technique used in this paper is SHAPE3D, which parameterizes how close the reconstructed beads are (in shape) to a perfect sphere. The results given in Figure 1 show that the iterative methods deal better with dataset with fewer radiographs, whereas the FDK method is adequate for scans with 256 radiographs or higher. Examining the differences between solutions FDK64 (Box 1) and CGLS64 (Box 2) in Figure 1: despite the dataset reconstructed is the same, the results differ significantly. In fact, the fewer radiograph artefacts are so severe that both FDK64 and FDK128 solutions (Boxes 1 and 3, respectively) are not segmented correctly, and thus show volumetric reconstructions of broken beads.

Analytical methods are fast, reliable, and popularly used by the tomography community. However, the results indicate that analytical methods cannot deal with the insufficiency in tomographic data, and the compensation of the missing data in a reconstructed image is achieved with the use of iterative reconstruction methods.

## Session 2: Understanding Materials

# Studying the fracture process zone in a heterogeneous brittle material (polygranular nuclear graphite) by synchrotron computed tomography, image correlation and X-ray diffraction

**James Marrow**

**University of Oxford**

Nuclear graphite is treated as a linear elastic material in engineering design; Graphite is, however, a heterogeneous quasi-brittle material, with non-linear mechanical behaviour and the development of a micro-cracked fracture process zone, which can cause strength to vary with size. Small test specimens from nuclear graphite, which are extracted either from operating reactors or used in material test reactor (MTR) accelerated experiments, provide the data to predict the performance of structural components; it is necessary to have confidence that such small specimen tests are representative and conservative. The objective of this work is to better understand how the microstructure of a coarse grained polygranular graphite accommodates applied strain, and the effect of this applied strain on its mechanical properties. To study this, it is necessary to be able to observe, *in situ*, the relationship between the applied strains, the total strains in the material's microstructure and the elastic strains in the crystals.

This presentation summarises progress in work to observe deformation and fracture in nuclear graphite, using synchrotron X-ray tomography and digital volume correlation to measure three-dimensional strain fields. High precision synchrotron diffraction studies on strained samples and the fracture process zone of propagating cracks provide new insights into the inelastic deformation of graphite. Micro cracked fracture process zones are common to quasi-brittle materials as diverse as high toughness monolithic ceramics, polymeric and natural biological composites, geological minerals and even volcanic structures. Experimental methods that support the study and modelling of damage development are thus important to a wide range of problems, beyond nuclear graphite.

## Mapping grains in 3D by laboratory X-ray diffraction contrast tomography

**Samuel A. McDonald,** Christian Holzner, Peter Reischig, Erik M. Lauridsen, Philip J. Withers, Arno Merkle and Michael Feser

**University of Manchester**

The majority of metallic and ceramic engineering materials of interest are polycrystalline. The properties of these materials can be significantly affected by behaviour at the length scale of the crystalline grain structure. The ability to characterise this crystallographic microstructure, non-destructively and in three-dimensions, is thus a powerful tool for understanding many facets of materials performance. The technique of X-ray diffraction contrast tomography (DCT) using monochromatic X-ray beams of very high flux found at 3rd generation synchrotron sources has been shown to be capable of mapping crystal grains and their orientations in 3D non-destructively. Clearly given the much wider availability and accessibility of laboratory X-ray microtomography systems the development of a laboratory DCT technique is an attractive prospect. Here we describe a new commercial laboratory X-ray DCT modality which has been enabled, and present some early experimental results. Firstly, we explore the capability of the technique by studying a titanium alloy (Ti-β21S) sample having an average grain size around 38 μm. The individual grain locations and orientations are reconstructed using the lab-DCT technique. These results are independently compared to measurements from both synchrotron phase contrast tomography (for grain locations) and electron backscatter diffraction (for grain orientations). One of the advantages of X-ray DCT over destructive methods of mapping grains in 3D is the ability to track grain orientations and sizes over time (e.g. '4D' studies). An example of this capability is provided by following the sintering of 100 μm diameter copper particles at a temperature of 1050°C, through a series of time lapse lab-DCT measurements. Local diffusion and deformation-related shape changes of the sintering particles are captured using conventional absorption tomography. At the same time, lab-DCT enables particle rearrangements (rotations and translations) as well as competitive grain growth from particle to particle through the sintering cycle to be tracked. Figure 1 shows grain maps reconstructed from lab-DCT scans of a copper powder sample at two different time steps. The grains are represented by cubes showing their positions in relation to the sample absorption mask. Revealed are the crystallographic orientation of the grains and their relative size. Individual cubes representing the grains can be followed between time steps and are observed in general to increase in size on applying a sintering heat treatment, indicating the degree of grain growth that has occurred. The aim is to give an improved understanding of the extent to which the different mechanisms contribute towards densification during sintering and their influence on the final microstructure, which should be controlled for optimal performance of components produced via the powder metallurgical route. This new laboratory based method could have a wide range of applications as well as supporting 3D polycrystalline modelling of materials performance.

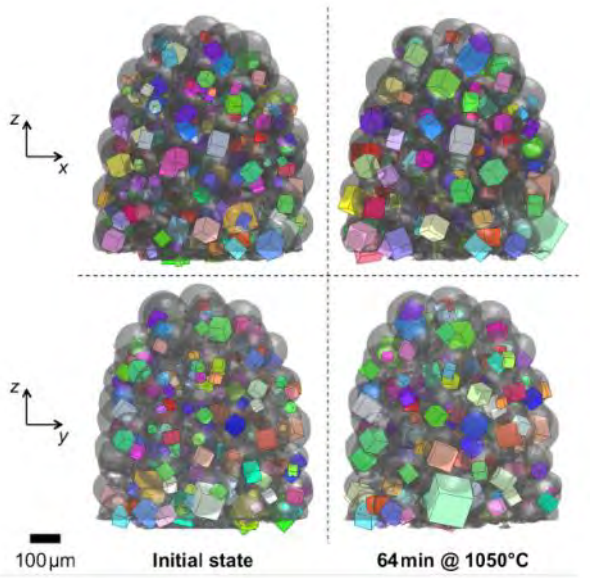



Figure 1. Reconstructed grain maps from two different time steps. The grains are plotted as cubes at their measured positions within the absorption mask of the sample, which is shown transparent, revealing their (relative) size and crystallographic orientation (by colour).

# Optimizing In situ synchrotron X-ray phase contrast tomography for the study of electrochemical lithium microstructure formation

**David S. Eastwood,** Paul M. Bayley, Hee Jung Chang, Paul R. Shearing, Clare P. Grey, Joan Vila-Comamala, Christoph Rau, Philip J. Withers and Peter D. Lee

**University of Manchester**

Microstructures in three dimensions is technically challenging due to the low density of lithium, which renders it almost transparent to conventional X-ray tomography. At the Diamond Manchester Imaging Branchline (I13-2) we used synchrotron X-ray phase contrast microtomography to perform 3D structural characterisation of lithium 'moss' or 'dendrites' formed within electrochemical cells. We observed microstructures formed under different charging conditions, providing new insights into the dendritic growth process which can occur in lithium batteries.

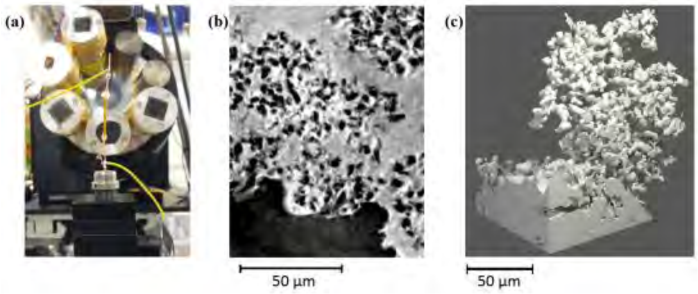



Figure 1. (a) the in situ electrochemical cell designed to allow 360° x-ray access for synchrotron micron-resolution tomography, (b) a slice through the tomographic reconstruction of a lithium metal (black) and electrolyte (white), and (c) a 3D surface rendering of a section of the metallic lithium showing the mossy structure.

Lithium dendrites or moss can form within batteries possessing metallic lithium at an electrode. The semicroscale lithium networks form electrochemically during the charging process, but are not symmetrically eroded when the current direction is reversed during discharge. An irreversible accumulation of lithium metal dendrites results, which has prevented the commercial adoption of lithium metal anodes in rechargeable batteries despite their very high theoretical energy density. Whilst various studies have been made of electrochemically deposited lithium microstructures using two-dimensional microscopy, there has been relatively little three-dimensional analysis, particularly within liquid electrolyte systems.

The I13-2 Diamond-Manchester Branchline offers intense monochromatic X-rays enabling high-resolution images to be obtained providing intricate details about the microstructure of lithium moss. These results represent the first 3D characterisation of electrodeposited lithium metal within the liquid electrolyte environment. The reconstructed images have sufficient contrast that they yield information on regions of differing electron density in the material, and we observed the formation of lithium compounds in addition to metallic lithium. Our micron-resolution images pave the way for highly detailed analyses of lithium moss, with a view to improving safety and battery life for future applications.

We used a monochromatic 19 keV parallel x-ray beam, providing strong in-line phase contrast imaging. The PCO 4000 camera provided a 0.45 µm effective pixel size, achieving ~1 µm spatial resolution. To create tomography volumes we first ran a phase back propagation filter on the sequence of 1800 images to reduce the phase effects, and then used a filtered back-projection 3D CT reconstruction algorithm. In addition to the low bulk density of lithium which creates limited absorption contrast, lithium is also unstable when exposed to air rapidly forming hydroxide, nitride, or carbonate compounds, which creates additional imaging challenges. By creating a sealed lithium-lithium cell within a 1 mm diameter kapton capillary tube it was possible to electrodeposit lithium.

# Anisotropic fracture in dentin under in-situ nanoscale 4-D imaging

**Xuekun Lu,** Robert S. Bradley, Benjamin Hornberger, Marty Leibowitz, Andrei Tkachuk, Sergey Etchin and Philip J. Withers

**University of Manchester**

High resolution x-ray tomography can enable the evolution of microstructure to be studied on the nanoscale. We report on the development and application of a new in-situ micro mechanical test rig, specifically designed to be accommodated within x-ray nanoCT scanner. The device was used to study progressive crack growth in dentin in different orientations, and thereby provide insights into the relationship between microstructure and anisotropic fracture toughness.

Dentin is a nano-composite material which forms the bulk of the mineralised tissue in human teeth. The mineralised component, hydroxyapatite, is believed to provide strength while the organic collagen matrix contributes to toughness. A key feature of dentin is the presence of tubules, which run from enamel layer to the pulp chamber, are microscopic channels occupied by odontoblasts during dentinogenes is. The micro mechanical test rig was applied with an indenter to initiate and propagate cracks within elephant dentin parallel and perpendicular to the tubules. At each progressive stage, x-ray nanotomography was used to characterise the evolution of the cracks with respect to the tubules. Quantitative analysis and digital volume correlation (DVC) based on the CT data were carried out to provide insight into the anisotropic fracture behaviour and crack shielding mechanisms.

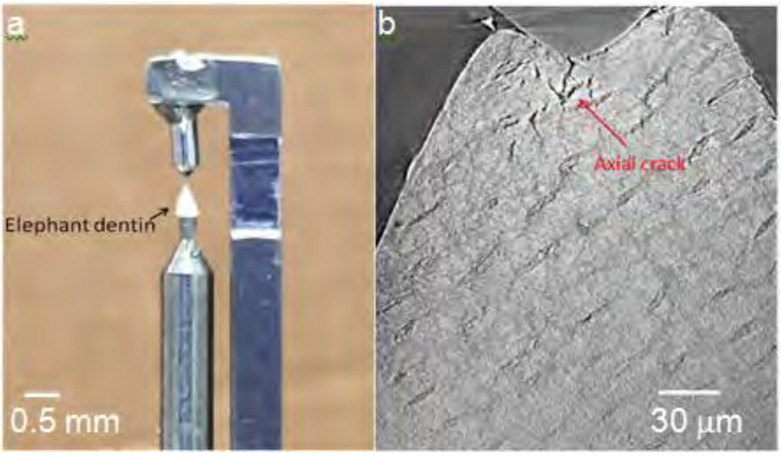



Figure 1. (a) The alignment of the micro indenter and the elephant dentin used for the experiment; (b) An orthoslice of the dentin data showing the crack generated by the indenter in depth direction

# Session 3: Data Handling and Visualisation

## 5TB a Day and Counting, Addressing the Data Deluge at Diamond Light Source


### Mark Basham

#### Diamond Light Source


Diamond Light source, the UK's National Synchrotron facility now has over 5 experimental stations collecting tomography data of one form or another. One of Diamond's core principles is that as a user facility, visiting scientists should be able to return from their visit with fully reconstructed data, preferably being able to see the results of their data collections minutes after the scan collecting the data has finished. With the incredible flux available at such a facility, the quantity of data collected on a daily basis at these beam lines is routinely above ten Terabytes a day. In addition to this, new methodologies and simplified data collection techniques drive the experimental researchers to devise more complex and richer experiments. The combination of these requirements and realities has driven the Data Analysis Group at Diamond to develop a new way to allow them to operate effectively. Savu is a massively parallel piece of pipelining software, written in Python and designed to be able to work under these harsh conditions. By making extensive use of existing libraries, coupled with Pythons natural ability to link with and incorporate existing software, Savu is able to address the performance and data volume issues presented above, whilst maintaining the flexibility and ease of use needed to stay relevant in this rapidly changing field.

## 3D Visualization for Data Exploration and Visual Assessment of Image Processing Results in Amira/Avizo


### Remi Blanc

#### FEI


Amira and Avizo are comprehensive, integrated software solutions for spatial data visualization, image processing, analysis and quantification dedicated respectively to life and materials sciences. Beyond the immediate visualization and exploration of possibly very large volumes, the visualization capabilities of Amira and Avizo serve most workflows related to imaging, constitute the primary component for assessing image processing results, enable several high-value supervised image processing techniques proposed by the software, and allow for a high impact presentation of these results. In this presentation, we will demonstrate the visualization capabilities of Amira and Avizo with respect to some major requirements among users of image-based solutions:

- very large / out-of-core data visualization: allowing the interactive handling of images possibly exceeding the available computer memory,
- visual presentation of quantified defects in metal castings: to quickly grasp the presence of critical defects and identify regions of special interest,
- alignment of multi-modal images: to enable visual pre-alignment, verify the quality of an alignment, exploit the different images to understand the imaged object,
- visualization of flow vector fields: get a visual impression of flows in porous media in addition to informative but difficult to interpret vector fields,
- estimation and visualization of fibres and fibre orientations in composites: in addition to vector or tensor fields, color-coding the extracted fibres or image regions gives immediate understanding of the materials architecture.

These will be illustrated on a variety of tomographic datasets across different disciplines from life and materials sciences.

## Feasibility of Simulated Annealing Tomography


### Nghia T. Vo

#### Diamond Light Source


Simulated annealing tomography (SAT) is a simple iterative image reconstruction technique which can yield a superior reconstruction compared with filtered back-projection (FBP). However, the very high computational cost of iteratively calculating discrete Radon transform (DRT) has limited the feasibility of this technique.

In this talk, I present an approach of quickly updating of the sinograms of an image corresponding to the change of its pixels without performing DRT using GPU (graphics processor unit). This technique can speed up SAT by several hundred times which improves its feasibility. Besides, the best of multiple-estimate (BoME) strategy is introduced (Fig. 1)to enhance the convergence speed of the reconstruction process. The performance of SAT under different conditions and in comparison with other methods is demonstrated by numerical experiments.

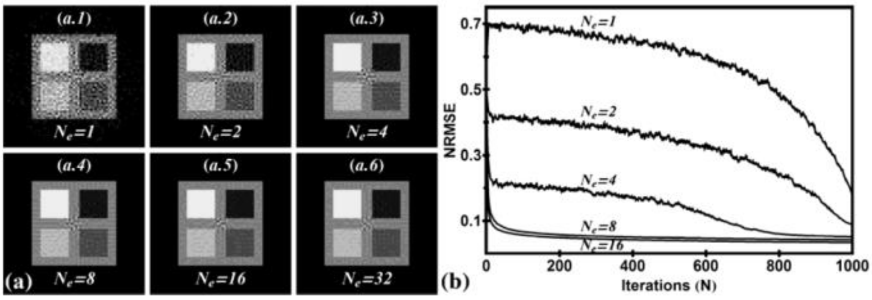



Figure 1. Demonstration of the BoME strategy where in the step of generation, there are Ne of the estimated images generated. The one giving the minimum of the cost function is chosen. (a) Reconstructed images from different Ne; (b) Comparison of the convergence speed at different Ne.

## Approaches for ring artefact suppression in CT


### Valeriy Titarenko

#### University of Manchester


Ring artefacts are main bottlenecks when one tries to segment a reconstructed volume. They appear as rings or circular arches of constant or varying intensity. Manual pre- or post-processing of projections or reconstructed slices is usually not possible due to a large number of artefacts. In practice some automated algorithms are needed to suppress them for a given type of a sample and known properties of a beam line or CT machine. Several algorithms have already been developed and allow users to process ``regular'' ring artefacts when their intensity does not depend on a rotation angle.

Today several new approaches are proposed. The first one is used to process artefacts on 2D projections unlike the original method applied only to 1D rows. The both algorithms are using analytical formulas and fast to implement as a software plugin. The second approach relates to modifying a data acquisition procedure in order to be able to track changes during the image recording state and split background images evolving differently during the scan. The third approach helps to suppress so-called “bright” ring artefacts which are caused by scratches or light-emitting dust particles on a surface of a scintillator. Unlike “regular” ring artefacts these “bright” ones have their intensity dependant on angle of rotation. Practical algorithms have been developed to suppress them.

# Session 4: Museum Science and Cultural Heritage

## STEAM-powered Imaging

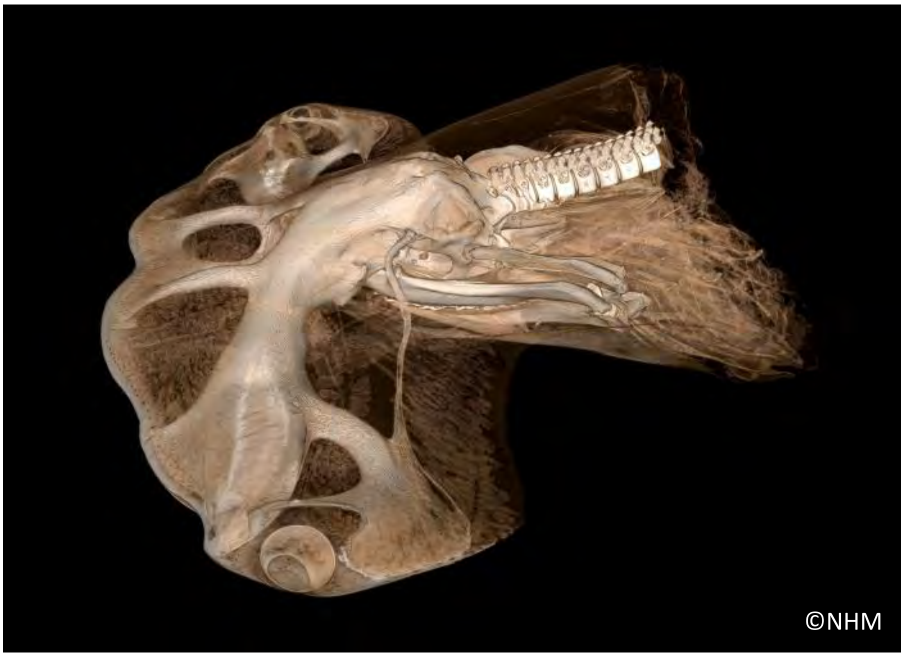
**Phillip Manning**

**University of Manchester**

Synchrotron-based imaging and x-ray microtomography is revolutionising how we study of life on Earth (both past and present). These de novo techniques are fuelling a rapidly expanding area of science that unites multiple disciplines (including physics, chemistry, maths, engineering, geology to name a few). The application of 21st Century technology to unpick the disjointed sentences that comprise the fossil record is now permitting there construction of past worlds in significantly higher fidelity. This wealth of interdisciplinary research has created the need for once disparate disciplines to share knowledge, techniques and terminology. Communication between these disciplines can often be difficult, but benefits are clear when partnerships are successful. The transfer of knowledge between disciplines might also aid and abet the engagement of much wider audiences and vice-versa.

There is no doubting the importance of engaging public audiences with Science, Technology, Engineering and Mathematics (STEM). The UK's Science, Technology and Facilities Council have embedded the public engagement of science into their central philosophy. The combination of imaging and fossils at Manchester has fed naturally into the intense public interest on the evolution of life on Earth but also integrating this with the underlying STFC-funded imaging research. Outreach programmes in this research-led area have been widely reported in traditional media as well as online, and through educational outlets such as museums.

There is a clear need to embed research-led engagement in our work so that we may encourage key audiences to follow careers in Science, Technology, Engineering and Mathematics (STEM). However, there is now an additional push to integrate the Arts into STEM, yielding the baroque acronym 'STEAM'. Will this latest approach to outreach aid and abet the translation of interdisciplinary science or might it just be hot air. There is certainly areal need to reduce the number of children who are moving away from STEM and/or STEAM subjects at all levels of education (from primary to degree level). It is quite possible that there are fresh opportunities to gain a better understanding of our science from engaging with public audiences. Such outreach might also help scientists better translate their research with each other across multiple disciplines.



# Bubbles in the Bullion – the microCT analysis of ancient coins

**Andrew J. Nelson,** Lisa Van Loon, Ute Wartenberg, Keith Barron, Bonnie MacLachlan and Neil Banerjee

**University of Western Ontario**

The earliest coins thought to have fiduciary value were made of electrum, an alloy of gold and silver, in Western Asia Minor in the middle of the 7th century BC, within the geographical and political context of the Lydian Empire. Lydia itself existed within the context of numerous Greek colonies in Western Asia Minor. Although monetary transactions had taken place before coinage in various, rather sophisticated forms, the advent of coins created new economic patterns and behaviour in the ancient world, which fundamentally remain in place to this day.

The research presented here is the microCT analysis of Lydian and later Roman coins in order to shed light on how the earliest coins were made. This research is part of a larger interdisciplinary project that seeks to place the origin of coinage within its cultural, economic and geological context to better understand this momentous event in our history. In addition to microCT, we are using synchrotron XRF and XRD mapping, scanning electron microscopy, and a suite of other techniques.

Previous workers have suggested that Lydian coins were very primitive and were produced by hammering naturally occurring electrum nuggets into staters. However, it is also possible that the electrum, an alloy of gold and silver, was purposefully created by mixing alluvial placer gold with mined silver. We undertook microCT analysis to address this question by examining the metal matrix of the coin.

The analysis of coins made from a gold/silver alloy using microCT presents a tremendous challenge. Preclinical microCT and synchrotron systems do not have sufficient kV to penetrate the matrix. Thus, industrial high power systems must be used, in this case a Nikon Metris XT-225 unit. However, even with high power, beam hardening and image artefacts complicate analysis.

In spite of these difficulties, we were able to obtain usable scans from several Lydian coins, and some later Roman coins which were scanned for comparison. The Lydian coins show a distinctive pattern of void spaces reminiscent of small bubbles in the alloy matrix that are likely produced by small amounts of gas that are liberated in the refining process. These bubbles are not visible in the later Roman coins, possibly reflecting an improvement in the refining process.

In this paper we will present the issues surrounding the imaging of early coins, the results obtained and we will present some hypotheses surrounding the minting process.

# A new dimension in documenting new species: High-detail imaging for myriapod taxonomy and first 3D cybertype of a new millipede species (Diplopoda, Julida, Julidae)

**Nesrine Akkari,** Henrik Enghoff and Brian D. Metscher

**Natural History Museum Vienna**

Taxonomic description, more than any other discipline, depends upon illustrations. From the earliest taxonomic treatments, species descriptions have nearly always been accompanied by visual representations, which are vital to convey information about the morphology and character states. We have described a new species of millipede (*Ommatoiulus avatar* n. sp., family Julidae) using high-resolution x-ray microtomography (microCT) for the first time as a substantive adjunct to traditional morphological examination. We present 3D models – cybertypes – of the holotype and paratype specimens and discuss the potential of this non-destructive technique for documenting new species of millipedes and other organisms. The microCT data have been uploaded to the Dryad open repository to serve as the first actual millipede cybertypes to be published. The idea of a cybertype – a digital simulacrum of a physical type specimen – has been discussed extensively in the recent literature and at a number of international meetings. As a supplement to the biological material, a cybertype adds value to the material collections and facilitates sharing of primary biodiversity data, reducing the reliance on handling of physical specimens to allow a new species to be included in more research efforts.

These millipede cybertypes comprise two high-resolution contrast-enhanced 3D tomographic images of the holotype (male) and one 3D image of a female paratype. Tomographic sections were reconstructed with pixel sizes and slice thicknesses of 1.7 µm or 2.0 µm (isotropic voxels) and 8-bitdepth using the Xradia software (XRMRecontructor, v. 8.1). The window and level values for the images were chosen in the reconstruction to include the complete brightness range of the samples, and these values were not adjusted further in the cybertype image stacks. Contrast staining with iodine imparts clear x-ray contrast to the non-chitinous tissues in arthropods and is easily removed with 70-90% ethanol – a common storage medium for arthropod specimens. Thus even for irreplaceable museum specimens, we can take advantage of microCT's ability to produce complete, size-calibrated, fully aligned volume images of intact samples, which are not damaged by the processing. This is the first new species description to be based partly upon and presented with a virtual representation (an avatar) of the holotype and paratype specimens. The species description presented here is another example of how the practice of taxonomic science need no longer be seen as quaint and old fashioned, but as a discipline that reflects the ways that knowledge is produced, shared, and used in our modern era.

## Archaeology meets Computed Tomography-Examination and Uncovering of a Celtic Princess

**Nicole Ebinger-Rist** and Henry Weber

**Landesamt für Denkmalpflege**

Since 2007 the Landesamt für Denkmalpflege Baden-Württemberg (LAD) has gathered extensive experience in the use of 3D computed x-ray tomography (XCT) for investigating and documenting archaeological finds, with very good results. Having standardised the application of this method the LAD is now able to draw on XCT in many research questions, investigating objects of a wide variety of materials, mostly from block excavation, prior to or even instead of their conventional manual extraction. Currently the LAD is putting its great experience in the use of this method at the service of the largest-ever block excavation project in Germany, the princess tomb of Heuneburg. Discovered in2010 around 2.5 km southeast of Heuneburg castle in the Danube valley the tomb has now been excavated as a single block weighing 80 tons.

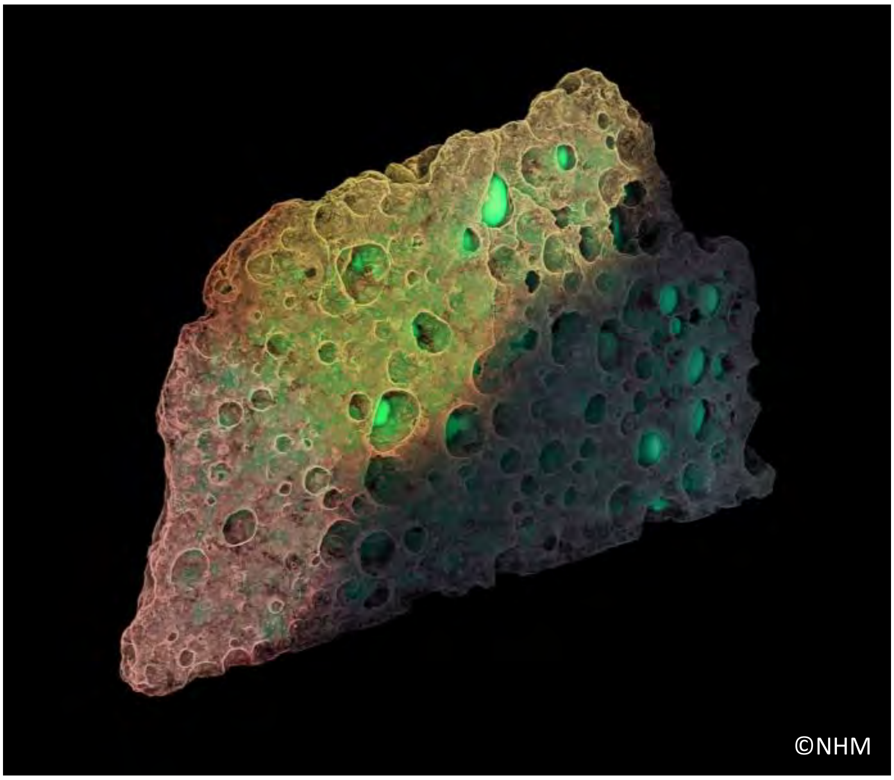
In the case of the princess tomb extracting sub-blocks was impossible because the site was wet-preserved, making it difficult to discern boundaries for safe excavation. Furthermore, some finds or findings in the scanned areas were located only a few centimetres or even millimetres away from the heavy oak board floor of the burial chamber. It was therefore decided to excavate the burial chamber as a whole. The initial stages of excavation yielded gold finds and finds of amber. The amber was in an unusually good state of preservation, whereas the bronze finds were in a very poor state, often only manifest as a shadow on the soil surface. Iron had not lasted at all in the burial chamber. After months of excavation work over the entire area the burial chamber exhibited different degrees of preservation. Due to the complexity of the main burial area with its diversity of materials such as gold, amber, jet and bronze in the hip region and the overlying organic matter it was decided to remove the princess from her resting place on three oak boards and analyse the oak boards by XCT. The first measurements yielded remarkable findings which could never have been obtained using a conventional approach. It would not have been possible to separate these complex layers with their rich content of diverse materials by manual means without considerable loss of information. Even materials which at first sight appeared completely decayed, especially bronze objects, had left shadows on the surface which proved capable of three-dimensional representation and in some cases even complete virtual reconstruction. The lecture deals with the scope of the method and presents first results from the virtual excavation, documentation and reconstruction of the early Celtic princess tomb.

# Micro Computed Tomography as an Enhancement Tool in the Curation of Apollo Samples

**Ryan Zeigler**

**NASA**

Recently, micro computed tomography (micro-CT) has been utilized as a part of the basic curation process for meteorites, largely spearheaded by the Natural History Museum (NHM). With the aid of our colleagues at the NHM, we have scanned 11 Apollo samples to investigate the applicability of micro-CT to the curation of Apollo samples. Initial scans have shown that we are able to readily identify diverse lithic clasts within polymict Apollo samples and use the scans as a guide to most efficiently subdivide the breccias to extract the lithic clasts, which are then made available to scientists for scientific studies. By combining micro-XRF analyses with micro-CT scans, we can add true compositional information and more fully characterize the newly identified clasts. Moreover, we have been able to use the scans to identify the textures within lithic clasts, locate rare or sought after minerals within samples, and identify fractures or other weaknesses within the samples (which aids in extraction of clasts). Additionally, micro-CT can be used to extract purely scientific information, such as large-scale porosity, on large Apollo samples while maintaining their pristine nature. This will enable scientific study on samples too large to be externally allocated to an investigator.



## How much, how far? Volcanic ash measurements using XMT deliver next-generation near-real-time dispersal prediction potential

**Matthew J. Pankhurst,** John A. Stevenson, Loic Courtois and Graham R. Davis

**University of Leeds**

An urgent challenge for volcanologists is the accurate and timely prediction of volcanic ash dispersal through the atmosphere. The hazard presented by volcanic ash to air travel, public health and knock-on effects such as damage to economies will grow as the global population expands and interconnects. Short-term weather system predictions have improved markedly in the last 5 years, but considerable uncertainty remains over the rate at which volcanic ash falls from the plume. An important factor that controls the terminal velocity is the particle shape. Natural ash grains can fall three times more slowly than the dense spheres that are typically used to represent them in models in operational settings.  Another is particle density, which is controlled both by composition and vesicularity and can vary widely between ash grains. To date, it has not been possible to collect these data directly, and instead extrapolations from 2Ddata have been used, following a time-consuming sample preparation routine.

Here we present a method for the timely production of statistically robust, 3-dimensional, ash size, shape and particle-specific densiometric measurement, applied to proximal ash erupted from Merapi Volcano, Indonesia, in 2010. These data were produced by setting the ash in a quick-setting resin to promote physical separation of particles in a low attenuation material, and scanned using the custom built MuCAT 2 scanner at Queen Mary University of London. The X-ray generator was set to 90 kV and 180 µA, voxel size was 12.5 µm. 2007 projections were collected over 11 hours with an effective exposure time of 7 seconds (actual data acquisition time was longer due to the use of time-delay integration). Densiometric calibration was performed with a virtual SiO2 phantom, according to protocol presented in. We used a workflow comprised of standard image processing techniques to segment and reduce the data to a handful of key parameters incl. particle density on an individual-particle basis. We used Electron Probe Microanalysis to verify mineral and glass compositions and thus independently constrain density: voxel brightness at the University of Leeds.

The data were used to calculate fall velocities for a large population of individual particles(>>10,000). The results demonstrate how 'real' particle shapes travel much farther than dense spheres and demonstrate the range of fall velocities for particles within a single sample. These data help quantify the uncertainty in dispersion model outputs.

We are now employing this method to a) characterize the range of proximal and distal volcanic ash present in the Holocene record, b) accelerate total workflow time and c) conduct higher resolution studies to resolve highly vesicular samples. We report on progress here.

This method provides a powerful new-tool to decrease epistemic uncertainty in ash dispersion models. It allows the 3D shape, internal vesicularity and magma composition to be measured, on a per-particle basis, for large particle population in a matter of hours. We anticipate that our work will lead to XMT system installation in volcano observatories, for use in crisis scenarios, and also to characterize the 'back catalogue' of eruptive activity of chosen active volcanoes to build an empirical record with which to compare with inevitable future activity.

# Synchrotron-based mapping of bioenvironmental signatures in fossils

**Victoria M. Egerton,** Roy A. Wogelius, Nicholas P. Edwards, Uwe Bergmann, and Phillip L. Manning

**University of Manchester**

The formation and preservation of fossils reflects the interplay of inorganic and organic chemical processes that begin at the moment of death. The ~50 million year old Green River Formation (Wyoming, USA) is well-known for the exceptional preservation of vertebrates such as fish, amphibians, reptiles, birds and mammals. It has not been fully understood whether structures such as feathers and skin are merely preserved as: impressions, chemically replaced organic structures (either through bacterially mediated films or inorganic replacement), the original organic residue (or their breakdown products) from the organism or a possible combination of the three. A new coliiformem bird (mouse bird), AMNH FARB 30806, from the Green River Formation has been analysed using synchrotron x-ray fluorescence and environmental scanning electron microscopy with an attached x-ray energy dispersive system (ESEM-EDS) in order to further determine the type of preservation (impression, chemically replaced or original organics) of this bird.

SRS-XRF is a powerful method for mapping dilute concentrations of elements. This non-destructive technique is ideal for fossils as it rapidly scans (up to 3000x faster than conventional element mapping techniques) to high sensitivity (parts per million) on large specimens without risk of damage. The concentration and distribution of 16 elements (Si, P, S, Cl, K, Ca, Ti, Mg, Fe, Ni, Cu, Zn, As, Br, Ba, Hg) has been mapped across AMNH FARB 30806. S, Cu and Zn map distinctly within visibly preserved feathers on the fossil bird and X-ray Absorption Spectroscopy (XAS) shows that S and Cu within the feathers are organically bound in a similar manner to modern feathers, most likely from the remnants of keratin and eumelanin, respectively. Inorganic geochemical precipitates, Mn, Ba, Br, and Ni, are also present and are distributed along bones and feathers. This study shows that it is possible to identify and quantify the organic remains overprinted by geochemical precipitates. For example, Mn has been revealed as an Mn oxide, birnessite or closely related mineral, rather than an organometallic chelate even though it appears to be distributed within biological structures. Additionally, this study shows that it is possible to clearly differentiate endogenous organic remains from those representing exogenous overprinted geochemical precipitates and illustrates the chemical complexity of the overall taphonomic process. Synchrotron-based imaging provides the crucial analysis must be conducted in order to accurately unpick the taphonomic history of fossils, using the quantification and distribution of chemistry to provide insight to the biology and biochemistry of ancient life.

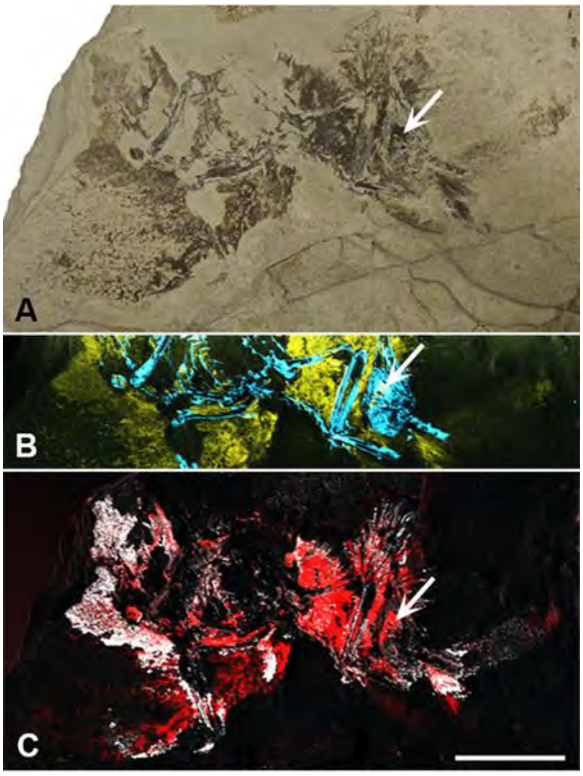



Figure: AMNH FARB 30806. (A) Coliiformes bird (AMNH FARB 30806) from the Green River Formation, Fossil Butte Member. (B) SRS-XRF elemental map with phosphorus (blue) and sulfur (yellow) distinctly showing bone with higher intensities of phosphorus and the feathers containing higher intensities of sulfur. (C) Copper (red) and manganese (white) elemental map where both appear to map within the feathers; however results indicate that copper is organically bound while manganese is an inorganically bound precipitate. (A-C) Upper arrow is pointing to the orbit (eye socket). Scale bar = 5 cm.

## X-ray micro-CT imaging of Cryptogamic Mineral Substrates: a novel approach to categorising the structure and interactions between mineralogical material and primitive terrestrial organisms

**Ria L. Mitchell** and Paul Kenrick

**The Natural History Museum**

Today, Cryptogamic Ground Covers (i.e., communities of mosses, liverworts, lichens, algae, fungi, and bacteria), are early colonisers of fresh, unstable, and potentially nutrient-poor ground surfaces. In addition to the ancient geological extent (~3000 million years) of some forms of bacteria, a growing body of data from molecular phylogenetics and the fossil record indicate that comparable associations of lichens and liverworts were colonising the land during the substantial 'greening' of the Earth in the Early Palaeozoic, some 460 million years ago. CGCs are thought to play an important role in the stabilisation of sedimentary surfaces where they form Cryptogamic Mineral Substrates; thin substrates hosting cryptogamic organisms which do not have features indicating substantial pedogenic development and weathering, and consequently should not be termed 'soil'. CMS's are also implicated in the onset of biotically-induced weathering (e.g., silicates, phosphates),pedogenesis, and soil formation, which has a significant impact on global geochemical cycles (e.g., carbon, nitrogen). Our goal is to understand how Cryptogamic Mineral Substrates develop, the contribution of cryptogams to substrate weathering, and how they mature and progress to true soils in an in-situ scenario, with a view to using them as modern analogues of early soil ecosystems.

Here, we x-ray micro-CT ~8 cm micro-cores and rocks samples collected from unstable and primitive land-surfaces in Iceland and New Zealand. We primarily focused our collecting on volcanic substrates from a variety of habitats including geothermal hot-springs, basaltic lava fields, glacial lateral moraine, volcanic ash-dominated desert plains, lake margins, earthquake-induced debris slumps, glacial outwash alluvial systems, and scoria cones. Cryptogamic organisms are widespread on loose mineral and volcanic-fragment substrates where they can thrive without much competition from 'higher' (vascular) plants.

Samples were scanned using a Nikon Metrology HMX ST 225 micro-CT Scanner at the Natural History Museum, London. A tungsten reflection target and a 0.5mm copper filter was used (3142 projections; 708ms exposure; 200kV and 140µA). Reconstructions were processed by CTPro software (Nikon met., Tring) and the data was rendered using Drishti, VG Studio Max and Avizo. Results provide insights into the biotic interactions governing the formation of Cryptogamic Mineral Substrates, including how organisms colonise, inhabit, bind and weather substrate and inorganic matrix. We are able to characterise the spatial distribution of sedimentary lithics, fines and porosity, and to show how these elements interact with the organic components, to a resolution of 11µm. We are also able to non-destructively reconstruct Cryptogamic Mineral Substrate physical structure. Importantly, key components (e.g., sedimentary lithics and the below-ground plant representation in the form of roots and rhizoids) can be extracted from the volume for individual analysis.

Results show: i) the surprising extent and depth of internal basalt boulder weathering by moss rhizoids and associated fungi ii) how lower, buried portions of plants stabilise grains (moss), trap grains (moss), and anchor to substrates and grains (liverwort rhizoids); and finally iii) Cryptogamic Mineral Substrate composition and the formation of complex systems of biotic and abiotic interactions, with buried organic matter particularly contributing to substantial amounts of substrate biomass. Our approach is directly applicable to characterising ancient Cryptogamic Mineral Substrate ecosystems, thereby contributing towards our understandings of the early development of life on land.

# Session 6: CT and Complementary Techniques

## X-ray diffraction tomography and 3D strain mapping

**Stuart Stock**

**Northwestern University**

X-ray absorption is not the only signal that can be used in Computed Tomography (CT). X-ray scattering differences can also be used in reconstruction and provides a very different map of structure. Since 2008, synchrotron x-ray diffraction tomography has been used increasingly for non-invasive mapping of crystallographic phases. This talk describes how: Diffraction patterns now are routinely reconstructed for each voxel within the slice. Rietveld refinement is used to produce maps of lattice constants and crystallite size. Loading-induced strains are mapped quantitatively while specimens are under load. The focus of the examples is on hydroxyapatite (hAp) the mineral in bone. The first example is a phantom consisting of pairs of bars containing very different hAp particles. The second example is strain mapping within rat vertebrae loaded in compression. The talk concludes with discussion of current 3D data collection rates and how these are being improved.

## High resolution serial sectioning tomography

**Bartlomiej Winiarski,** Tim L Burnett, Teruo Hashimoto, George E. Thompson and Philip J. Withers

**University of Manchester**

Ultramicrotomy and Plasma FIB combined with SEM imaging are discussed with respect to their ability to fill an important gap in high resolution, high contrast analysis of >100 $\mu m^3$ volumes. X-ray tomography is the 3D imaging technique of choice for a wide range of materials science applications including metals. Despite the significant developments in the areas of diffraction contrast tomography (DCT), 3DX-ray Diffraction (XRD) and colour X-ray tomography there are still many instances when it is necessary to employ destructive 3D analysis techniques.

One of the stand out advantages of serial sectioning techniques is that it allows high resolution observation of the microstructure, allowing observation of subtle variations in crystallography and chemistry with resolution down to a few nanometres. It is also possible to introduce quantification of the crystallography and chemistry through combination with electron backscatter diffraction (EBSD) and energy dispersive X-ray spectroscopy (EDX) respectively. This makes it a key capability in linking to microscale X-ray CT and adding complementary information and scale.
The current gap in our ability to investigate materials in 3D for >100 $um^3$ volumes with high resolution has been a severe restriction for many materials science applications, for example, the grain size of many important metals is in the 10's of µm range.

In this paper we will present two serial sectioning approaches that allow large volume serial sectioning with high resolution imaging to help bridge this gap. Ultramicrotomy uses a diamond knife to mechanically slice material away from a prepared block face. Implemented within an SEM where each newly revealed block face is imaged in high resolution. The limitation is that ultramicrotomy is limited to relatively soft materials, however we can effectively analyse aluminium and magnesium across volumes 100's of microns in size. Lastly we introduce results from a Plasma FIB-SEM which uses a Xe plasma ion source. The range of materials investigated so far includes Ni, stainless steel, aluminium, tungsten carbide and zirconium and for which we have implemented automated serial sectioning routines with cross sections over 100 µm in width and depth and ~100 nm slice thickness to extract meaningful volumes of information covering many grains. The creation of 3D EBSD datasets using this approach is making completely new insights possible. The machining capabilities of the Plasma FIB have also meant that site-specific pillars <100 µm diameter suitable for Nano X-ray CT can be routinely made providing a key link to this scale of X-ray CT imaging.

## Distilling principal relationships of 3D tiling arrangements in growing mineralized elasmobranch cartilage.

**Ronald Seidel,** David Knötel, Daniel Baum, James C. Weaver and Mason Dean

**Max Planck Institute**

The endoskeleton of sharks and rays (elasmobranchs) is comprised of a cartilaginous core, covered by thousands of mineralized tiles, called tesserae. Characterizing the relationship between tesseral morphometrics, skeletal growth and mechanics is challenging because tesserae are small (a few hundred micrometers wide), anchored to the surrounding tissue in complex three-dimensional ways, and occur in huge numbers. We integrate material property, histology, electron microscopy and synchrotron and laboratory µCT scans of skeletal elements from an ontogenetic series of round stingray Urobatis halleri, to gain valuable insights into the generation and maintenance of a natural tessellated system. Using a custom-made semi-automatic segmentation algorithm (see Knötel et al abstract), we present the first quantitative and 3d description of tesserae across whole skeletal elements. The tessellation is not regular, with tesserae showing a great range of shapes, sizes and number of neighbours. This is partly region-dependent: for example, thick, columnar tesserae are arranged in series along convex edges with small radius of curvature (RoC), whereas more brick- or disc-shaped tesserae are found in planar/flatter areas. Comparison of the tessellation across ontogeny, shows that in younger animals, the forming tesseral network is less densely packed, appearing as a covering of separate, poorly mineralized islands that grow together with age to form a complete surface. Some gaps in the tessellation are localized to specific regions in all samples, indicating they are real features, perhaps either regions of delayed mineralization or of tendon insertion. We will use the structure of elasmobranch skeletons as a road map for understanding shark skeletal mechanics, but also to extract fundamental engineering.

## Spectroscopic X-ray tomography for 3D chemical imaging

**Philip Withers** and Christopher K. Egan

**University of Manchester**

Recent technological developments in energy sensitive X-ray detectors has enabled the coupling of X-ray imaging and X-ray spectroscopy. By integrating these detectors into laboratory computed tomography systems the X-ray attenuation spectrum of a material can be measured with positional sensitivity. Step changes in the measured spectrum signify the position of absorption edges which issued as a fingerprinting tool to yield specific atomic number sensitivity. By recording energy sensitive projections and reconstructing the data we can obtain a 3D view of the internal chemical content inside the sample object. Example applications of spectroscopic X-ray tomography will be presented covering the distribution of catalytic metals supported on porous substrates for industrial scale chemical processing; and mapping of chemical elements and minerals inside geological core samples.

# Analysis of bone structure and strength using micro- Computed Tomography and Finite Element techniques

**Bert van Rietbergen**

**Eindhoven, University of Technology**

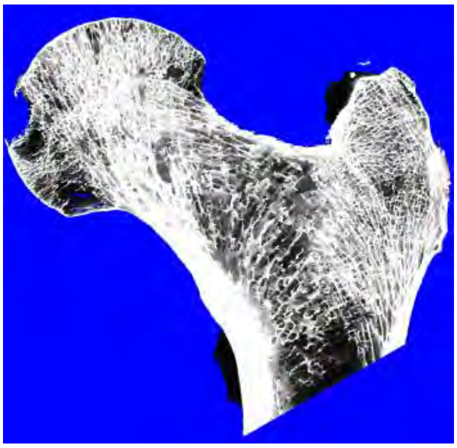
Bone tissue, which forms the skeleton, is a remarkable material. It displays a wide variation in architecture, varying from dense and compact (cortical bone) to highly porous structures built of a complex network of struts and plates (trabecular bone) (Fig. 1). In clinical practice, the density of bones in these porous regions as measured, e.g. by DXA, is considered as a measure of osteoporosis, which is an affection of the skeleton that leads to loss of bone mass and strength. However, bone density is not an accurate predictor of bone strength. This is likely because it does not account for the bone microstructure and loading conditions.

With the introduction of micro- Computed Tomography (micro-CT) some 2 decades ago, it has become possible to create high-resolution (~50 microns) 3D reconstructions of porous bone. Nowadays, this is possible even for bone in-vivo, albeit at limited sites. Based on such models, accurate morphological parameters can be measured. Whereas such parameters well summarize the bone architecture, they are not necessarily good predictors of bone strength either.

With the later development of micro- Finite Element (micro-FE) techniques based on micro-CT scans, it has become possible to get direct and accurate measures of bone strength. With the most common of these techniques, voxels in the 3D reconstruction are directly translated to brick elements in the micro-FE model such that the models represent the actual bone microstructure. These models then can be used to simulating mechanical tests. Compared to real experiments, the micro-FE approach has the advantages that it enables the simulation of experiments that are difficult or impossible for real bone specimens, that it can provide complete information about bone elastic properties, and that it can provide information about the loading at the level of the bone tissue, which is what the bone cells sense.

Since micro-CT is also possible in-vivo, micro-FE can also be used to simulate mechanical tests for bone in animals or patients. In combination with image registration techniques, it even is possible to correlate locations of bone loss and gain with local loading conditions, thus to test 'Wolff's law' for bone remodelling at the bone tissue level.

The purpose of this presentation is to provide an overview of the techniques and discuss recent developments. Discussed will be ‘basic science applications’ such as the determination of physiological bone tissue level strain distributions in human bones and in bones of other (extinct) species. Also, some clinical applications will be discussed, such as the determination of bone strength in osteoporotic patients and the assessment of bone consolidation during fracture healing.



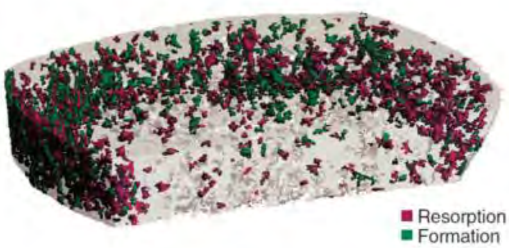



Figure 1. micro-CT reconstruction of a human femur cut in half to show the trabecular bone (top) and regions of bone formation/resorption measured in-vivo for a 9 mm slice of the distal tibia using image registration of 1-year follow-up images (bottom)

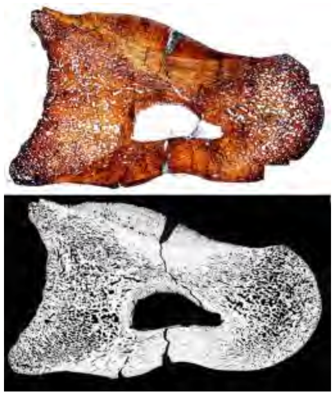
# Abstracts - Friday 4th

## X-raying bones in the 21st century


### Jennifer Anné

#### University of Manchester


Current understanding of bone healing and remodelling strategies in vertebrates has traditionally relied on optical morphological observations through the histological analysis of thin sections. However, chemical analysis may also be used in such interpretations, as different elements are known to be absorbed and used by bone for different physiological purposes such as growth and healing. In addition, the different chemical inventories within a specimen can highlight specific features that can be used to better visualize and interpret fine structures within fossil biological tissues.  These chemical signatures are beyond the detection limit of most laboratory-based analytical techniques (e.g. scanning electron microscopy). However, synchrotron rapid scanning–X-ray fluorescence (SRS–XRF) is an elemental mapping technique that uniquely combines high sensitivity (ppm), excellent sample resolution (20–100 µm) and the ability to scan large specimens (decimetre scale) approximately 3000 times faster than other mapping techniques.



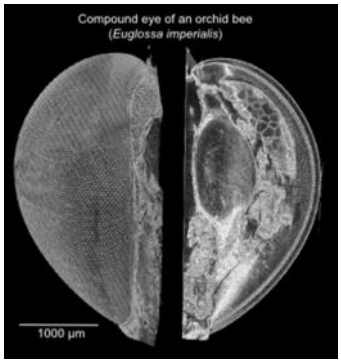
Allosaurus phalanx (toe) thin section exhibiting a fracture callus on the dorsal surface.  Viewed in optical light (top) and in phosphorus (XRF elemental map; top).

Here we present a de novo approach to histological interpretation through chemical imaging (chemohistology) using a combination of SRS-XRF at the Stanford Synchrotron Radiation Light source (USA) and microfocus elemental mapping at the Diamond Light source (UK) to determine the distribution and concentration of trace elements within pathological and normal bone of both extant and extinct archosaurs (*Cathartesaura* and *Allosaurus fragilis*). Results reveal discrete chemical inventories within different bone tissue types and preservation modes. Chemical inventories also revealed detail of histological features not observable in thin section, including fine structures within the interface between pathological and normal bone as well as woven texture within pathological tissue.

## Using microCT to see through an insect's eyes


### Gavin Taylor

#### Lund University


Insects use visual information from their eyes to control many behaviours, ranging from avoiding obstacles to chasing prey.  We are quantifying the eye morphology of a range of insects from different habitats. This will allow us to identify how visual specializations have evolved with the different habitats preferences and behaviours observed in different insect species. To this end, we have performed microCT of preserved insect eyes at laboratory and synchrotron x-ray sources. These scans have provided us with high-resolution (0.3 – 5 µm) information on the full three dimensional morphology of the eyes of over 30 tropical and temperate insect species, and allow us to identify anatomical features of the eyes that directly relate to the visual capabilities of specific species. For instance, the size and curvature of lenses define the field of view of the underlying photoreceptors, whose sensitivity is defined by their width and length. Datasets are segmented, with the resulting volumes used to compute of the optical properties of different eye regions. In this project, microCT has provided a high throughput method of quantifying the small optical and neuroanatomical structures that compose the eyes of insects. The results of this study will ultimately provide insights into how visual systems have evolved to suit different habitats.

NATURAL HISTORY MUSEUM

MANCHESTER 1824
The University of Manchester

# Contrast enhanced Micro-CT of the heart; applications in functional micro-anatomy and electrical modelling

**Robert Stephenson,** Petros Kottas, Jichao Zhao, Caroline Jones, Rafael Guerrero, Philip Withers, Mark Boyett, Henggui Zhang, George Hart and Jonathan C. Jarvis

**Liverpool John Moores University**

Scientists strive to improve our understanding of the 3-D micro-anatomy of the heart, and to provide 4-D explanations of contractile and electrical function. The cardiac walls are often described as a 'complex mesh', consisting of axially coupled contractile myocytes (cells approximately 80µm x 20µm) which form intricate spiralling and branching chains, often termed 'fibres'. These myocyte chains are embedded in a connective tissue matrix, and aggregate to form identifiable muscle bands in the atria. In the ventricles they form interleaving and heterogeneous stacked aggregations, termed lamellar units.

Anatomically and biophysically-detailed mathematical models of cardiac function are a powerful tool for functional and therapeutic investigation of the heart in 4-D. However there is a lack of high-quality micro-anatomical data available to bioengineers. Powerful bioengineering groups have expended huge efforts to produce highly detailed electrophysiological data to inform their models, but the fidelity of the resultant models is compromised by poor geometric data.

The best method of resolving functional anatomical issues is to produce high resolution 3-D and 4-D representations derived from actual structures. Due to shortcomings of both traditional histology and dissection, and modern magnetic resonance imaging, such data has not been attainable with satisfactory morphological detail. Using contrast enhanced micro-CT data of ex vivo normal and failing mammalian hearts, we ask how the micro-anatomical structure of the heart generates the dynamic changes that underlie electrical function in health, and dysfunction in failure. We show how the gross anatomy of the heart is changed in heart failure, including region-specific hypertrophy, dilatation and stretch (fig.1A). We reveal the intricate 3-D micro-anatomy of the atrial muscle bands, their hierarchical arrangement, and how they are remodelled in failure. Using eigen-analysis of the 3-D structure tensor we present 3-D myocyte orientation at resolutions approaching the individual myocyte (~5-20µm) (fig.1B), and show the striking regional heterogeneity that exists. Accurate high resolution 3-D representation of myocyte orientation is essential due its effect on the propagation of electrical depolarisation; conduction is faster along myocyte chains than between them. Novel and existing anatomical, molecular, and electrophysiological data is then amalgamated to create anatomically and biophysically-detailed mathematical models of normal cardiac electrical function. Data from failing hearts, including the associated anatomical and molecular remodelling is then modelled. In both normal and failing hearts, electrophysiology more closely represented the in vivo state when 3-D myocyte orientation was assumed to provide the principle direction for the wave of depolarisation (fig.1D) than when depolarisation was assumed isotropic (fig.1C). In the failing heart, consistent with clinical presentations, models predicted a greater incidence of conduction slowing and conduction block, conditions associated with re-entry formation, tachycardia and fibrillation.

Micro-CT provides data superior to existing methods for the investigation of whole organ micro-anatomy, producing data with superior resolution in a non-destructive and time-efficient manner. This data improves the fidelity of mathematical models and gives insight into the roles structural complexities and the intricate orientation of myocytes play in normal electrical propagation, and when remodelled by pathology, their role in the generation of life threatening electrical abnormalities.

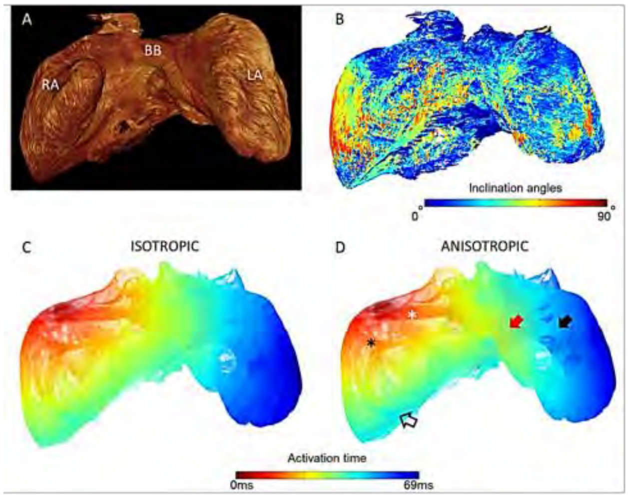



Figure 1- The role of myocyte orientation on electrical propagation in the atria. Volume rendering of rabbit atria produced from micro-CT data (A), used as geometry for isotropic simulation (C). Myocyte orientation plot extracted from micro-CT data (B), and used for anisotropic simulation (D). Isometric resolution of micro-CT data ~22 µm. For anisotropic simulations conductivity was set at 9.0 mS in themyocyte chain direction and 0.9 mS transverse. For isotropic modelling, conductivity was assumed equal in all directions. The seed point of electrical stimulation was from the centre of the sinoatrial node. Preferential conduction through muscle bands and improved synchrony is observed in anisotropic conditions. Modelling was conducted by Dr Jichao Zhao, The University of Auckland. BB-Bachmann's bundle, LA- left atrium, RA- right atrium. White asterix- cristae terminalis, Black asterix- septum spurium, Open arrowhead- anterior right atrium, Red arrow head- Bachmann's bundle, Blackarrowhead- pectinate muscles of left atrium.

ZEISS FEI™ CCPi Tomographic Imaging Nikon

## Medical applications of Micro-Computed Tomography: New Diagnostic Possibilities

**J. Ciaran Hutchinson,** Neil J. Sebire, Andrew T. Ramsey, Michael T. Ashworth and Owen J. Arthur

**Great Ormond Street Hospital**

Due to high radiation exposures and the requirement to immobilise specimens for long periods of time, micro-CT has not transitioned to become a diagnostic imaging tool in routine medical practice but it may be particularly useful in histopathology. Microscopic dissection of small specimens is technically difficult, prone to error in sampling and interpretation, and by its very nature, destroys the tissue under examination. In both macroscopic evaluation of tissue samples (biopsies or resected tumours, for example), and in conventional autopsies, the ability to acquire images with resolutions similar to a light microscope would represent a significant improvement in practice.

As part of a larger ethically approved project into less invasive autopsy procedures, we present a series of 4 cases examined using micro-CT including forms of congenital heart, lung and kidney disease, with a direct comparison of histological appearances. Specimens were immersed in potassium tri-iodide prior to micro-CT examination. Images were acquired using micro-CT scanners with a multi-metal target system (Nikon Metrology, Tring, UK). Scans were reconstructed using proprietary Nikon software (CTPro 3D) and processed using VG Studio MAX (Volume Graphics GmbH, Heidelberg). The resultant virtual anatomy was analysed by experienced paediatric pathologists and paediatric radiologists.

All specimens demonstrated excellent internal tissue contrast and all micro-CT scans acquired provided the necessary level of detail to make an accurate morphological diagnosis without the need for further dissection. In the case of congenital heart disease, some features (myocardial integrity, coronary sinus) were better identified on micro-CT examination than at macroscopic dissection. In the cases of congenital lung and kidney diseases, the level of resolution provided by micro-CT examination enabled diagnosis and sub-typing of the disease category from the micro-CT data alone. Imaging of the thymus demonstrates further potential added value of micro-CT by segmenting out the microvascular anatomy of the organ without the need for injected contrast. No diagnostically relevant findings were missed by evaluation of data generated by micro-CT examination.

These data show that micro-CT has the potential to provide clinically useful imaging information for a range of organs, with visualisation similar to that of conventional histopathology. Micro-CT has the additional advantage of creating a permanent 3D dataset that could be sent for second opinions as well as allowing pre-dissection analysis of the correct dissection approach and potential assessment of surgical margins. Traditionally, pathologists infer diagnostic information about three-dimensional pathological processes occurring within an organ from 2-dimensional glass slides; with further optimisation, micro-CT may become a routine step in the analysis of complex specimens where volume relationships may alter clinical diagnoses. The addition of micro-CT imaging to our workload of 5000 histopathological examinations and 500 autopsies performed at our institution per year could represent a significant improvement to clinical services. Micro-CT has the potential to change the way in which early fetal miscarriages and terminations (<24 weeks gestation) are performed and recorded.

NATURAL HISTORY MUSEUM

MANCHESTER 1824
The University of Manchester

# Session 8: Data Quantification

## Extending the value of X-ray micro-CT for quantitative analysis

**Adrian Sheppard,** Shane Latham, Andrew Kingston, Glenn Myers, Trond Varslot, Andrew Fogden, Vanessa Robins, Mohammad Saadatfar, Anna Herring, Ryan Armstrong, Christoph Arns and Tim Senden

**Australian National University**

With the ability to image the interior of complex and porous materials at the micron scale in 3D, X-ray micro-CT has tremendous potential to characterize microstructure and help us achieve a quantitative understanding of the relationships between material microstructure and macroscopic properties. However, unlocking this potential involves far more than simply acquiring data, since raw gray-scale images as produced by micro-CT scanners are mere maps of attenuation, and qualitative maps at that. The first step in realising the full potential of x-ray imaging is to improve the quality of the input datasets by reducing artefacts and noise, and moving towards images with quantitative, repeatable grayscales. The ANU micro-CT facility uses very high cone angles, enabled by a unique double-helix scanning trajectory, to maximise the signal-to-noise ratio. In addition, several strategies have been developed for minimising imaging artefacts and maximising repeatability. Even with a high quality image there will be aspects of the sample that are difficult to distinguish, either due to in sufficient resolution or X-ray contrast. These issues can be tackled by increasing the attenuation of some materials in the sample, and registering the 'before' and 'after' images to quantify the resulting image change. We have developed several novel labelling (staining) strategies, targeting porous geomaterials but of wider applicability. Finally, improved image analysis of critical importance, most notably the step of image segmentation, and so a new segmentation method based on bilateral filtering and modified statistical region merging is being developed.

## Moving CT out of the Research Department and onto the Production Line

**Andrew Ramsey** and Noémie Ganet

**Nikon Metrology**

Industrial Computed Tomography was first developed in the late 1980s and grew in use as a laboratory research tool in the 1990s and 2000s. Many people who have used CT scanners in the past are used to waiting an hour or more for their scans to complete, another half an hour or more for reconstructions, several minutes for volumes to load and then they may spend an hour or more analysing the results.

Today, CT scans can take only a few minutes, or even less than a minute; reconstructions less than one minute; analyses only seconds. What took two hours 15 years ago now takes less than two minutes. The resolutions used then were good enough to inspect many parts and yet today we often spend the same two hours getting far higher resolution than is needed to inspect a particular part. By choosing our regions of interest carefully, reducing the resolution slightly and increasing the power of our X-ray sources we can inspect at the same quality as a decade ago yet do it fifty times more quickly.

This opens up a whole new world of possibilities, moving CT inspection out of the research laboratory and onto the production line. By designing CT scans efficiently, storing scan parameters so they are easily retrievable together with analysis parameters too (automatic macros using measurement templates and GD&T) a whole series of CT scans of different types of parts can be done by operators with very little training. In fact, by loading samples with a robot human intervention up to the point of reviewing the results can be removed completely.

This paper will introduce fast CT scanning, even at high resolution using powerful microfocus sources, suitable for batch inspection, or in some cases, 100% inspection.

# Quantifying dynamic rheology, phase interactions and strain localisation in magmas using high-speed x-ray tomography

**Kate J. Dobson,** Donald B. Dingwell, Fabian Wadsworth, Jeremie Vasseur, Sebastien Wiesmaier, Ed J. Llewellin, Felix Von Aulock, Rajmund Mokso and Julie L. Fife

**Ludwig-Maximilians-Universität München**

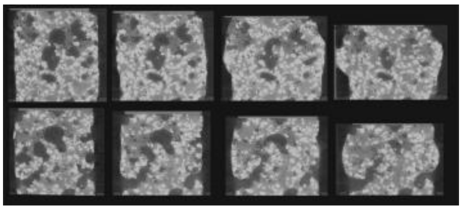


Figure 1. 2D render of the same vertical slice through the spatially registered 4D set showing compression of a three phase magma at 850ºC.

Magmatic cargoes of crystals and bubbles are critical controls on magma mobility and rheology, but vary in time and space, making local and bulk behaviour strongly heterogeneous. Tracking their evolution and interactions during deformation is a critical challenge in volcanology, as these processes control many phenomena, including melt-crystal segregation, degassing, strain localisation, and fragmentation. The only methodology available to track these processes in real time, at the appropriate scales is high-speed x-ray tomography.

We present data from recent experiments at the TOMCAT (Swiss Light Source) beam line, and it is some of the very first data to be acquired using the worldwide-unique giga FROST high-speed detector. The giga FROST has the same chip as the pco. DIMAX camera but provides continuous acquisition of images at 8GB/s; in other words, the memory limitation from the DIMAX has been removed. We coupled this with the new laser-based heating system available at TOMCAT, which has two lasers incorporating larger spot sizes (4mm wide by 6mm high) and maintaining 150W of power each, which are ideal for rapid, isothermal heating.

Working with 3D image acquisition speeds of less than 3 seconds, and collecting data over the 0-180 sector of every rotation, we have been able to acquire a series of scans over a long duration of time (>1h) that captures both the high and low frequency dynamics.

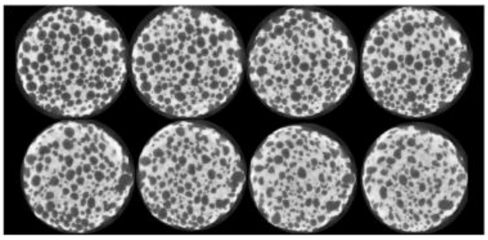


Figure 2. 2D render of the same horizontal slice through a spatially registered 4D set showing bubble interaction and morphological evolution during isothermal heating at 900ºC of a natural obsidian sample. Each image was acquired in 3 seconds, every 20th image is shown (1 minute between images shown).

We performed deformation experiments on both synthesized and natural bubble-melt, and crystal- bubble-melt systems at magmatic temperatures, in order to observe the microstructural evolution. Initial constant strain rate experiments performed on a synthesized anhydrous basaltic melt (temperature dependent viscosity, temperatures of 800-1100ºC, melt viscosity ranges of over 6 orders of magnitude) seeded with a variable concentration of non-reactive crystals and bubbles (30-70 volume %) have been supplemented with samples deforming under constant load. Each 3D image took ~3 seconds to acquire (Fig. 1).

We demonstrate how the time-resolved data can be used to trace the location and local distribution of the suspended bubble and crystal phase (Fig. 1 & 2), which enables us to define spatially heterogeneous and dynamic local bulk viscosities. We will show how this time-resolved 4D information can be used to investigate the implications of spatially- and temporally-variable rheological behaviours, and with it, how we are able to quantify the dynamics of magmatic processes from melt mobilisation, to fragmentation and sintering.

Session 8: Data Quantification

# Characterising the neck motor system of the blowfly


## Peter Swart

### Imperial College


Flying insects use visual and mechanosensory information provided, for instance, by the compound eye and halteres to control their movements, both when on the ground and airborne. Exploiting visual information for motor control is significantly simplified if the eyes remain aligned with the external horizon. In blowflies (*Calliphora vicina*) and many other insects, the eyes are fixed inside the head, therefore stabilising the gaze amounts to stabilising the entire head. In fast flying insects, head rotations relative to the body enable gaze stabilisation during high-speed manoeuvres when the animal changes its flight trajectory or during externally caused attitude changes due to turbulent air.

However, in previous behavioural studies into gaze stabilisation, the interpretation of the result suffered from the fact that the dynamic properties of the supplying sensor systems and those of the neck motor system were convolved. In other words, the transfer function describing the neck motor system was not independently accessible and was formalised based on assumptions rather than experimental data. Specifically, stabilisation of the head in response to induced thorax roll involves feed forward information from the halteres, as well as feedback information from the compound eyes. To fully understand (and improve) the functional organisation of the fly gaze stabilisation system, we need to investigate the neck motor system independently.

Through X-ray computed microtomography (µCT), high resolution 3D data has become accessible, and through staining techniques developed in collaboration with the Natural History Museum, highly detailed anatomical data can be extracted. Specifically, each neck muscle was individually segmented out from the surrounding tissue along with their attachment points into the cuticle at both ends and rendered in 3D. Once combined, this resulted in a full 3-dimensional anatomical representation of the 22 neck muscle pairs and neighbouring cuticula structures which comprise the blowfly neck motor system.

Currently, this rich data being used to infer function from structure by creating a biomechanical model (unfinished) of the neck motor system from the CT data. This will be used to determine the specific function of each muscle individually, and ultimately perform a dimensionality reduction of the fly neck motor system to inform the design of artificial gaze stabilisation systems.

## Bioengineering and Life Sciences

| Code | Author | Title |
|---|---|---|
| 001 | Dr Daniel Martin-Vega<br>*The Natural History Museum* | Estimating the Age of Blowfly Pupae with Micro-Computed Tomography – A Novel Method in Forensic Practice |
| 002 | Dylan Smith<br>*Imperial College* | Exploring miniature brains using novel techniques in micro-CT scanning |
| 003 | Allison Luger<br>*Max Planck Institute* | On the jaws of Lamniform sharks |
| 004 | Júlia López-Guimet<br>*Universitat de Barcelona* | Synchrotron X-ray micro-tomography of aged and diseased cardiovascular tissues |
| 005 | Catherine Disney<br>*University of Manchester* | X-ray micro tomography of intervertebral discs |

## CT - Past, Present and Future

| Code | Author | Title |
|---|---|---|
| 006 | Dr Leah Lavery<br>*Carl Zeiss* | Approaching Realism – What you can do with 3D X-ray Microscopy? |
| 007 | Nadia Kourra<br>*University of Warwick* | The future of CT in Aerospace Industry |

## Data Quantification

| Code | Author | Title |
|---|---|---|
| 008 | Dr Tristan Lowe<br>*University of Manchester* | Time dependent variations in X-ray Computed Tomography |
| 009 | Dr Robert Bradley<br>*University of Manchester* | A new technique to estimate the noise and bias in measurements made from tomography scans |

# CCPi Poster competition

## CT and Complementary Techniques

| Code | Author | Title |
|---|---|---|
| 010 | Dr Nicholas Edwards<br>*University of Manchester* | Imaging the Chemical Fossil Record |

## Data Handling and Visualisation

| Code | Author | Title |
|---|---|---|
| 011 | Dr Sheng Yue<br>*University of Manchester* | Non-destructive quantification of additive manufactured metal parts using X-ray microtomography |
| 012 | Dr Erica Yang<br>*STFC Rutherford Appleton* | ULTRA a HPC data analysis platform for CT reconstruction and visualisation |
| 013 | David Knötel<br>*Zuse Institute Berlin* | Segmentation of the tessellated mineralized endoskeleton of sharks and rays |

## Earth and Space

| Code | Author | Title |
|---|---|---|
| 014 | Ery Hughes<br>*University of Bristol* | Volcanic eruption dynamics of pantellerite melts |
| 015 | Dr Mattia Pistone<br>*Smithsonian Institute* | How much, how far? Volcanic ash measurements using XMT deliver next-generation near-real-time dispersal prediction potential |
| 016 | Dr Kate Dobson<br>*Ludwig-Maximilians-Universität München* | Going down the tubes complex kinematic indicators in tube pumices revealed by X-ray tomography |
| 017 | Elizabeth Evans<br>*Swansea University* | Applying x-ray microtomography to the field of tephrochronology |
| 018 | Natasha Almeida<br>*Natural History Museum* | Quantifying Deformation of Chondrules in the Leoville Meteorite Using X-Ray Micro-CT |
| 019 | Neil Adams<br>*Royal Holloway* | Fossil Fruits of the London Clay A New Insight from X-Ray Analysis |
| 020 | Neil Adams<br>*Royal Holloway* | The Taxonomy, Taphonomy and Tomography of Miocene Cissus from Kenya |

# Understanding Materials

| Code | Author | Title |
|---|---|---|
| 021 | Dr James Carr<br>*University of Manchester* | Nanoscale 3D imaging of porous micro-silver joints for quantitative characterization of porosity evolution and determination of elastic properties by the finite element method |
| 022 | Dr Stephen Price<br>*Diamond Light source* | Microfocus Multimodal Chemical Tomography at Diamond Light Source |
| 023 | Xun Zhang<br>*University of Manchester* | Characterization of porosity and its effects on thermal conductivity in plasmas spray coatings using X -ray µ-tomography |


We would like to extend our thanks to The Natural History Museum, The University of Manchester, The Royal Microscopical Society, our sponsors, our speakers, the ToScA planning committee, Manchester local committee and volunteers, and all the delegates.

*-Team ToScA*

NATURAL HISTORY MUSEUM

MANCHESTER 1824

The University of Manchester

RMS